Evaluation of measures to promote urban renewable energy use.

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Evaluation of Measures to Promote Urban Renewable Energy Use

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ABSTRACT

Within the current context of the UK's commitment to reducing carbon dioxide emissions, a clear understanding of the nature of the problems, obstacles and complexities facing the implementation of renewable energy technologies, in particular, in urban areas is urgently required. Technical and economic obstacles are often regarded as the most important problems facing the use of renewable energy technologies. However, with the promise that the most significant technical and economic obstacles will be overcome in the foreseeable future, it is essential to determine whether any other obstacles exist. Given a better insight into what key stakeholders, namely energy suppliers and end users, expect from energy supplies and services, respectively, it is possible to have a clearer understanding of the issues involved with such non-technical and non-economic obstacles. Whilst technical and economic considerations should not disregarded, a systematic approach, which encompasses a means of establishing different stakeholder expectations, provides an analytical tool with which to assess the ability of the existing energy system and renewable energy technologies to satisfy the energy requirements of stakeholders.

Using Sheffield as a case study example, the relative potential contribution which renewable energy could make in reducing carbon dioxide emissions is assessed by means of an energy study. This provides a helpful framework for identifying key areas of energy consumption and carbon emissions, ways of reducing energy consumption through energy efficiency measures, and the impact of utilising local renewable energy resources. Substantial opportunities for reducing carbon dioxide emissions throughout Sheffield are established, especially in connection with utilising renewable energy technologies to supply energy efficient buildings.

Both renewable energy technologies and energy carriers, which are relevant to Sheffield, are examined systematically. This involves establishing the technical and economic status of passive solar design, active solar systems, photovoltaics, wind power, biomass energy and small-scale hydro technologies, followed by an evaluation of each technology against the relevant stakeholder demand criteria. The key issues facing the utilisation of existing energy carriers of electricity, gas networks and district heating systems, all of which link energy supply to demand, are also examined. The uses of hydrogen as a new energy carrier are explored in more detail to establish the technical and economic status of hydrogen technologies and its performance against the stakeholder demand criteria.

The result is a better understanding of the nature of the obstacles facing the implementation of renewable energy technologies in Sheffield. In addition to technical and economic issues, the influence of wider non-technical and non-economic obstacles on the uptake of renewable energy technologies in Sheffield is considered. Solutions to the problems are put forward and their likely ability to promote the implementation of renewable energy technologies in urban areas is briefly assessed. The overall outcome is that the potential exists for Sheffield and other urban areas in the UK to utilise local renewable energy resources provided that effective solutions, such as those proposed here, are instigated to ensure that established stakeholder expectations are met in full.

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Finally, I would like remember Trudi, Tara, Billy and Barbara and dedicate this thesis to my grandparents.

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1. INTRODUCTION

1.1 Context

In recent years, there has been growing interest in renewable energy and its long-term contribution to energy provision in the United Kingdom (UK). This interest has been stimulated by environmental and sustainability concerns over the use of fossil fuels, namely coal, oil and natural gas, and nuclear energy sources. The burning of fossil fuels releases carbon dioxide emissions, a major contributor to global climate change along with other greenhouse gases. Research has shown that on a global level, the energy sector is the largest single source of carbon dioxide emissions and 40% of all greenhouse gas emissions are released from the combustion of fossil fuels (PIU, 2002). The signing of the Kyoto Agreement in 1997 signified an important step in seeking to reduce greenhouse gas emissions at an international level. Based upon a recommendation by the Royal Commission on Environmental Pollution (RCEP), the UK has set a target to reduce carbon dioxide emissions by 60% below 1990 levels by 2050 (RCEP, 2000 and DTI, 2003a). In addition to the problems of producing energy from fossil fuels, nuclear energy also poses serious environmental issues. Whilst nuclear energy is carbon neutral, its production results in radioactive waste and long-term risks of contamination. In the UK, the current energy system relies heavily on these conventional energy sources. Fossil fuels and nuclear energy contributed 89% and 9% respectively to primary energy production in the UK in 2002 (DTI, 2003a).

The reliance on fossil fuels and nuclear energy also raises issues over the sustainability of using such resources. Sustainability principles indicate that it is important for the UK to continue to develop without irreversibly damaging the environment, both now and in the future. The finite nature of fossil fuels and nuclear energy and the environmental problems associated with their use, makes them unsustainable. Although renewable energy sources only contributed 2% to primary energy production in the UK in 2002, they display a number of key characteristics which makes them more preferable than conventional energy resources (DTI, 2003a). Firstly, renewable energy sources, such as solar energy, wind power and biomass, are naturally replenished as they are consumed, so they never run out (IEE, 1994). Secondly, renewable energy sources are carbon neutral. Thirdly, renewable energy is readily available across the UK. As the majority of energy consumers live and work in urban settlements, towns and cities have high concentrations of energy demand. The high energy demand also makes urban settlements responsible for associated carbon dioxide emissions. Although some renewable energy sources are site-specific, most are ubiquitous to all urban areas. One of the most commonly available renewable energy sources in urban settlements is solar energy. Other renewable energy sources, such as geothermal power, are specific to certain towns and cities. And finally, it is recognised that all energy developments have environmental impacts. With careful management, any adverse environment impacts of renewable energy developments can be successfully mitigated against.

Whilst there is a need to minimise the environmental and sustainability impacts of energy provision, there is a continuous need for energy. Energy is an essential part of every day life as it provides consumers with key energy services of heat, motive power and electrical-based services. Without a plentiful supply of energy, everyday life, that people are accustomed to, would cease to exist. As such, energy is a key driver of human activity and environmental change. In order to reconcile environmental and sustainability concerns with the continuous demand for energy, a fundamental shift in energy provision needs to take place. Whilst the utilisation of energy efficiency measures can help to reduce the demand for energy and lower associated carbon dioxide emissions, they only provide part of the answer. The rest of the answer lies with renewable energy sources. An energy system based on renewable energy sources would deliver energy to consumers whilst meeting environmental and sustainability concerns. In particular, carbon dioxide emissions would be significantly reduced. This is a more sustainable approach which will test the commitment of the UK in seeking a balance between energy and the environment. Although this approach may be more preferable, the adoption of renewable energy technologies as a basis for sustainable energy systems will require fundamental changes at all levels in society. Energy production, supply and demand must be modified in order to achieve sustainability. This will require urban areas to become responsible for local energy consumption, carbon dioxide emissions and managing the impacts of energy production.

At present, the use of renewable energy technologies, particularly in urban areas in the UK, is very low. Whilst the environmental and sustainable advantages of renewable energy have been widely recognised and acclaimed, there is a gap between an awareness of the advantages and the practical deployment of renewable energy technologies within communities. To date, renewable energy projects have been influenced by a wide range of different technical, economic, non technical and non economic obstacles. Each obstacle, as a single issue or a combination of issues, has influenced the uptake of renewable energy and any move towards sustainability. As such, any transition towards the wider deployment of renewable energy is faced with problems, complexities and a new set of challenges. The transition raises questions concerning the practical ability of renewable energy sources to meet local energy needs, reduce local carbon dioxide emissions and contribute to the sustainability of urban areas in particular. Also, it is debatable whether a transition towards a renewable energy system can take place using existing energy infrastructure. Given the complexities of the issue, a detailed examination of the problem is necessary on a local level.

1.2 Aims and Objectives

1.2.1 Aims

The aims of this thesis are to:

- Investigate the potential contribution which renewable energy technologies can make to the reduction of carbon dioxide emissions, specifically, and achieving sustainable development, generally, by their practical implementation in the urban environment with reference to Sheffield as a case study example, and

- Determine the most appropriate and suitable measures for promoting their deployment in towns and cities of the UK.

1.2.2 Objectives

The specific objectives of this thesis are to:

- Determine the energy expectations of different stakeholders and evaluate the existing energy system against these expectations,

- Review the current status of renewable energy technologies which are relevant to Sheffield in relation to their technological maturity, economic competitiveness and consider wider non-technical and non-economic issues,

- Determine prospective carbon dioxide savings which can be achieved by the application of relevant renewable energy technologies within Sheffield,

- Establish the technical, economic, non-technical and non-economic obstacles to the deployment of renewable energy technologies in Sheffield,

- Identify suitable measures for the practical promotion of renewable energy technologies in Sheffield, specifically, and the UK, generally.

1.3 Methodology

As indicated by the above aims and objectives, the evaluation of measures to promote urban renewable energy use addresses a wide range of issues across many disciplines. In order to prioritise key issues throughout the research, a systematic, multi-disciplinary approach has been adopted based upon a case study. Sheffield has been chosen as an example of a representative UK city for which a sound basis of essential data is available. In particular, this research builds upon existing energy assessment work on the "Municipal Integration of Renewable Energies" (MIRE), carried out in Sheffield by the Resources Research Unit of Sheffield Hallam University in 1992. The earlier work produced preliminary assessments of energy consumption and renewable energy resources in Sheffield and the surrounding area (Grant, 1993, 1994a, 1994b; Grant, Kellett and Mortimer, 1994a, 1994b, 1995a, 1995b; Grant et al, 1994c; Kellett, 1993, 1994a, 1994b; Mortimer, 1993, 1995 and Mortimer, Kellett and Grant, 1994). Policy and planning procedures for the implementation of local energy strategies intended to reduce energy consumption and associated carbon dioxide emissions were also investigated (Kelly and Mortimer, 1996). The case study provides a realistic quantifiable basis for exploring the practicality of producing energy from local renewable energy resources and acts as a framework for identifying the issues facing the deployment of renewable energy technologies within an urban area.

A programme of research has been produced in which a number of key tasks are identified. Each task provides the basis for the next or later stages of analysis. The first task is to identify who are the stakeholders and what do they expect from energy services. Qualitative research methods are used to analyse secondary sources on consumer research, green consumerism and company information and reports. From this examination, a list of stakeholder demand criteria are produced which identifies and defines the energy expectations of energy suppliers and end users. The existing energy system can then be evaluated against these criteria to identify areas of compatibility and incompatibility between current energy supply and demand. This information provides the necessary context of the thesis, and is the subject of Chapter 2.

If renewable energy resources are going to provide the basis for achieving sustainable energy systems within urban areas, it is necessary to explore the availability of local renewable energy resources and their potential contribution to reducing associated carbon dioxide emissions. Using Sheffield as a case study example, the second task is to produce an energy study for the district of Sheffield. Energy studies are used to determine current energy demands and carbon dioxide emissions and, in some cases, to provide a base for predicting energy savings and renewable energy opportunities. Previous energy studies have been produced for buildings, transportation, cities and regions (including Best Foot Forward, 2002; Cooper et al, 2001; Cosmi et al, 2003; Grant and Kellett, 2001, 2002a, 2002b, 2002c and Pout et al, 1998). There are many quantitative methods available for producing energy and carbon dioxide assessments. A review of the different energy assessment methodologies can be found in Appendix A. The Sheffield energy study uses existing methodologies from the MIRE study to allow for future comparison between the results. The Sheffield energy study comprises of three sections, namely a baseline energy assessment, an energy efficiency assessment and a renewable energy assessment. The methodology and results of the baseline assessment of energy consumption and associated carbon emissions in Sheffield can be found in Appendix B. The methodology and results of the energy efficiency and renewable energy assessments for Sheffield can be found in Appendix C and D, respectively. Energy use and associated carbon emissions in Sheffield are examined in Chapter 3. This includes defining the study area and summarising land use patterns, presenting the key findings of the energy study and summarising the implications of these findings for Sheffield. The opportunities for reducing carbon dioxide emissions through the use of locally available renewable energy resources are explored in Chapter 4. Ways of reducing energy consumption in buildings through energy efficiency measures are presented followed by an assessment of local renewable energy prospects and future energy use in Sheffield.

In addition to examining ways in which the utilisation of energy efficiency measures and local renewable energy resources can lower carbon dioxide emissions within Sheffield and contribute to the development of a sustainable urban energy system, the energy study also provides the basis for identifying available renewable energy resources in Sheffield. A range of different renewable energy technologies, which could be utilised to exploit renewable energy resources in Sheffield, are put forward and examined in turn. Using qualitative analysis, a comprehensive literature review of the renewable energy technologies applicable to Sheffield is undertaken. Although renewable energy potential may exist within an urban area, it can only be exploited if renewable energy technologies are technically and economically available. In addition, wider non-technical and non-economic issues may influence their utilisation. As such, this review seeks to answer the following questions; how can the technologies be used in an urban environment, what is the current status of the technologies and what issues influence their implementation within an urban settlement. Using a wide range of sources including books, journals, reports and internet website addresses, the renewable energy technologies of passive solar design, active solar systems, photovoltaics, wind power and small-scale hydro power are evaluated against the following criteria:

- Basic Aspects,
- Resource Considerations,
- Applications,
- Technical Status, and
- Economic Status.

Unlike other renewable energy resources, biomass energy is complex due to the diversity of the resource. In order to convert biomass energy into useful energy, different types of conversion technologies can be used depending on the type of biomass and the final output required. To ensure that all the necessary issues concerning biomass energy resources are fully explained, more detailed criteria are necessary:

- Basic Aspects,
- Resource Considerations,
- Biomass Preparation,
- Conversion Technology,
- Processing Technology,
- Outputs and Applications, and
- Economic Issues.

This detail can be found in Chapters 5 to 10, which examine solar energy technologies, wind power, small-scale hydro power and biomass energy, respectively. The basic aspects, resource considerations and status of each of the technologies are examined in the first half of each Chapter. The second half examines how renewable energy technologies currently differ from conventional energy technologies using the relevant stakeholder demand criteria as a benchmark for the analysis. This is necessary in order to clearly understand the differences between the ability of the technologies in meeting stakeholder expectations and to establish what would need to be in place, or what would need to change, if renewable energy technologies were utilised within Sheffield. The performance of the existing energy system and renewable energy technologies against stakeholder expectations are summarised in a table at the end of each chapter. A series of dots have been used to indicate where the existing energy system and renewable energy supply currently meet stakeholder expectations (3 dots), partially meet expectations (2 dots) and fail to meet expectations (1 dot). This analysis provides the basis for the identification of obstacles facing the deployment of renewable energy technologies in Sheffield. The obstacles relevant to each technology are discussed and summarised in a matrix at the end of each Chapter. Where applicable, a square symbol has been used to illustrate where the obstacle affects different stages of deployment.

In addition to exploring the characteristics and issues facing the implementation of renewable energy technologies, it is necessary to look at ways of linking renewable energy supply to demand through the utilisation of existing and future energy carriers. Electricity and gas are existing energy carriers within the UK. Alternative energy carriers which could be utilised in the UK are heating and cooling networks and hydrogen. At present, no single publication has been published on all relevant energy carriers and their role in the utilisation of renewable energy resources. As a result, a literature review of a wide range of sources including books, journals, reports and internet-based information is necessary. This review is needed to establish the current status of energy carriers in the UK and identify the key issues facing their utilisation in future renewable energy developments. The examination of existing energy carriers is provided in Chapter 11 followed by an examination of hydrogen as an energy carrier in Chapter 12. Electricity and gas networks are evaluated against the following criteria:

- Basic Aspects,
- Key Issues, and
- Future Developments.

As the use of district heating networks are less common in the UK, they are evaluated against more detailed criteria:

- Basic Aspects,
- Resource Considerations,
- Technical Status,
- Economic Status, and
- Additional Considerations.

Although hydrogen could be utilised as an energy carrier, questions are raised concerning how hydrogen could be produced and used in urban areas, the technical and economic status of hydrogen and what would need to be in place for the wider implementation of hydrogen in the urban environment. The evaluation of hydrogen follows the same format as that of each renewable energy technology. The first half of Chapter 12 evaluates hydrogen against more detailed criteria, as listed below.

- Basic Aspects.
- Resource Considerations,
- Production Technology,
- Storage and Transportation Options,
- Infrastructures and Appliances, and
- Economic Issues.

In the second half of the chapter, hydrogen is evaluated against the stakeholder demand criteria. The performance of the existing energy system and hydrogen against stakeholder expectations are summarised in a table at the end of the chapter. This analysis provides the basis for the identification of obstacles facing the use of hydrogen as an energy carrier in urban areas. The key obstacles facing hydrogen are discussed and summarised in a matrix.

The outcome of the above programme of work is the identification of a range of areas where renewable energy technologies currently fail to meet or partially meet the energy expectations of stakeholders. In Chapter 13, a summary of this earlier analysis is provided in two tables together with a discussion of the obstacles facing the deployment of renewable energy technologies in urban areas. Using qualitative research techniques, a series of measures for overcoming the obstacles are formulated and developed in detail. In order to consider whether the measures suggested may be suitable for promoting renewable energy developments in Sheffield, each measure is briefly assessed against each stakeholder expectation. A tick symbol has been used to illustrate which specific stakeholder expectation each measure could help overcome. Conclusions and recommendations for further work are presented in Chapter 14.

1.4 Terms and Definitions

1.4.1 Key Terminology

Most of the terminology used here is commonly used in the assessment of resources, energy consumption and carbon dioxide emissions and related environmental disciplines. The following sections introduce and define key terms and units of measurement used throughout this study.

1.4.2 Resources

Using a dictionary definition, resources can be defined as "a stock or supply that can be drawn on" (Thompson, 1995). The extent to which a resource base can be used as a practical energy source depends on the level of knowledge or information available and the economic feasibility of extracting and processing the resource. In order to distinguish between different resources, a simple classification system can be used:

- Resource base; the total quality of energy or power which physically exists in a recognisable form,

- Resources; the part of the resource base which could be developed under present or future economic circumstances using existing or modified current technology, and

- Reserves; the part of the resources which have proved to exist and which could be exploited under present economic circumstances (Grant, Kellett and Mortimer, 1994b).

The resource base is all the energy available from a given source. Normally, it is physically impossible to exploit the extra resource base. New resources are discovered, technological advances and changing energy prices affect the availability of resources and reserves. Reserves are essentially dynamic in nature due to fluctuating prices. As prices change and resource use becomes financially feasible, the size of resources changes very quickly (Grant, Kellett and Mortimer, 1994b).

1.4.3 Energy Sources

Energy sources fall into two main categories, renewable energy sources and non renewable energy sources. Renewable energy is a term used to describe a "source of energy which is naturally replenished as it is consumed" (IEE, 1994). Renewable energy sources include solar energy, wind power and water power. Whilst non renewable energy sources do replenish themselves, they do so at a rate which is so much slower than the rate of depletion in recent history that in effect they can be treated as finite stocks. Fossil fuels and nuclear energy sources are non renewable forms of energy. Fossil fuels are composed of carbon derived from plants and animals contained in sediments which are converted into coal, oil and natural gas over thousands of years. Nuclear energy is produced from radioactive materials such as uranium, which naturally occurs in minerals and rocks (Dineley et al, 1976).

1.4.4 Forms of Energy

There are three main forms of energy, primary energy, delivered energy and useful energy. In order to distinguish between each form of energy, the following definitions can be used:

- Primary energy; the amount of energy available in resources in their natural state, such as solar energy, wind power, coal, natural gas, oil and uranium deposits in the ground.

- Delivered energy; following extraction and processing, primary energy resources are converted into suitable forms of fuels and electricity which can be used by consumers, termed delivered energy. Liquid fuels, gaseous fuels, solid fuels, electricity and heat are the main forms of delivered energy. Electricity is a diverse energy resource which can be used for many applications including heating, lighting and motive power, and

- Useful energy; consumers use fuels and electricity in appliances, equipment etc., to provide useful energy such as heat, light, motive power, etc. Useful energy consists of space, water and process heating and cooling, light, motive power for transport and machinery and electrical-based services (Elsayed and Mortimer, 2001).

1.4.5 Energy Carriers

An energy carrier is a term which refers to a means of carrying or transporting energy from the point of production to the point of consumption. Commonly used energy carriers in the UK are electricity and gas which are distributed to consumers using national networks. In some parts of the UK and other European countries, such as Germany, water, air and steam are used as energy carriers within heating and cooling networks. Additionally, research is being undertaken in developing hydrogen as a new energy carrier.

1.4.6 Stakeholders

Within the urban environment, there are two main categories of stakeholder, namely energy suppliers and end users. Energy suppliers comprise of electricity utilities, gas companies and district heating suppliers. They supply end users with delivered energy and are responsible for matching supply to demand. End users, who are commonly referred to as energy consumers, consume useful energy in order to heat, cool, light or ventilate buildings, to operate appliances and machinery and to power cars and other modes of transport. End users can be placed into three broad categories or sectors, namely the domestic sector, the industrial sector and the transport sector. The domestic sector comprises of all domestic households within a defined area. Using a Standard Industrial Classification system (SIC), all economic activities of a similar nature can be classified into different industrial groups (CSO, 1992). Within this thesis, two broad groups are used which incorporate the SIC definitions; business and industry. Industry, as expressed in this thesis, relates to primary and secondary activities, for example, manufacturing of all types. The business sector is very varied and includes education, health care, office employment and repair services. The transport sector comprises of a number of different modes of road, rail and air transport.

1.4.7 Units of measurement

A variety of units have been used to measure energy consumption and carbon dioxide emissions. The following units have been used to measure energy consumption:

- Kilowatt hour (kWh): A unit of energy. 1 kWh is used when 1 kW of power is consumed for one hour. A kW is equivalent to 1000 watts (Max Fordham and Partners, 1999).

- Terajoule (TJ): A unit of energy equal to 10^{12} joules. A joule is a unit of energy equal to the energy released by an electrical current of 1 ampere driven by 1 volt for 1 second (DTI, 2001a).

Carbon dioxide emissions have been measured in terms of tonnes of carbon (tC). Carbon dioxide is released when fuels containing carbon are burnt, for example, coal, oil and natural gas. Different fuels have different carbon content which affects the amount of carbon dioxide released. In order to calculate carbon emissions, carbon coefficients are used. Carbon coefficients show the amount of carbon released per unit of energy available either upon combustion of the energy source or generation of electricity, for example, tC per TJ (Pout et al, 1998).

2. ENERGY IN CONTEXT

2.1 Energy Systems and Stakeholders

Within the UK, the existing energy system comprises of energy production, supply and consumption. Although the existing system can be split into three key areas, there are numerous interfaces between the production, supply and consumption of energy. The production and supply of energy and the role it has to play in the economic development of the UK has been widely documented. In addition, there has been considerable research on general consumer attitudes and behaviour when purchasing products and services. However, there appears to be limited research, if any, in examining the interface between end users, also referred to as energy consumers, and the energy system. In particular, the ability of the existing energy system to meet the energy expectations of end users has not been widely discussed. This examination is vital when considering the future deployment of renewable energy in the UK. If a future energy system based on renewable energy is pursued, this will have serious implications on the relationship between end users, the production and supply of energy and the overall success of the new system. This will also have implications for energy suppliers. As key stakeholders in the energy market, energy suppliers, also referred to as energy utilities, have expectations which must be addressed. Therefore, it is also necessary to take into account the expectations of energy suppliers when examining the existing energy system and certain renewable energy technologies.

In order to establish likely stakeholder perceptions, the expectations of end users (Section 2.2) and energy suppliers (Section 2.3) are explored. The existing energy system is then evaluated in light of stakeholder expectations in Section 2.4. Section 2.5 summarises the performance of the existing energy system against the expectations of end users and energy suppliers. This provides the basis for identifying key challenges facing the existing energy system. The future role of renewable energy technologies in the supply of energy in the UK is proposed and potential problems surrounding the deployment of renewable energy in urban areas are raised.

2.2 End Users

End users as consumers of energy expect a certain standard of energy service. The "expectations" of consumers have been the focus of consumer research undertaken by service suppliers, independent research organisations and social scientists (including

Roberts, 1996; Corrado and Hines, 2001; Customer Champions, 2003 and MORI, 2002). Consumer research has tried to identify and understand what really matters to consumers, what influences the decisions consumers make, i.e. consumer behaviour and attitudes, and how services can meet consumer requirements. This research has highlighted a number of key drivers behind consumer behaviour. Consumers expect a product or activity to be labour saving (easy to use) (Warde et al, 1998), convenient (Corrado and Hines, 2001; Ottman, 1994; Roberts, 1996 and Warde et al, 1998), of a certain quality (Corrado and Hines, 2001; Customer Champions, 2003; Ottman, 1994 and Roberts, 1996), affordable in relation to saving money, the price of products and getting value for money (Corrado and Hines, 2001; Customer Champions, 2003; Hobson, 2001; McGrath, 1992, MORI, 2002 and Roberts, 1996) and ethical (Corrado and Hines, 2001; Hobson, 2001; MORI, 2002; Roberts, 1996 and Warde et al, 1998). In relation to the provision of energy services, it is also logical to assume that stakeholders may also be motivated by the accessibility, or availability, or a product or service, and the ability of a service to meet a growing range of stakeholder needs whilst being consistent with existing services (Shaw, Mortimer and Kellett, 2004). Based upon this research, it is possible to compile a list of terms which could be used to describe end user expectations of energy services. From the end users perspective, the supply of energy services must meet the following criteria:

- Accessibility,
- Ease of Use,
- Flexibility,
- Convenience,
- Reliability,
- Consistency, and
- Acceptability.

The accessibility of energy services is important from the end users perspective. With a dictionary definition of "that can be readily reached, entered or used, readily available" (Thompson, 1995), energy services must be readily accessible and available all day, every day, wherever required. Energy is readily available to end users within buildings, filling petrol stations, etc. Electricity and natural gas are delivered directly to buildings using underground cables and pipes, respectively. Liquid fuels used for transportation purposes are available from filling stations, the majority of which are located in populated areas and are open for long periods up to 24 hours. The fuel is piped using a pump from storage containers located under the forecourt into the vehicle for immediate consumption. The existing supply system helps to support the notion that energy should be accessible at all times. Whilst there is some interaction between end users and energy, for example filling the car with fuel, they do not have the personal responsibility of worrying about how to obtain fuel. The existing infrastructure eases the supply of energy to end users.

Energy services are also regarded as easy to use by end users. Easy to use implies that energy is "not difficult" to use and can be used "without great effort" (Thompson, 1995). Appliances and equipment in the home, office and industrial buildings convert electricity or gas into useful energy such as light and heat (Elsayed and Mortimer, 2001). Additionally, engines in vehicles convert petroleum products into motive power. Whilst there is some interaction between end users and energy, consumers do not have to worry about how to convert fuel into useful energy services. Instead, the technology converts the energy into a useful form that is simple to use by almost everyone.

The flexibility of the supply of energy is an important end user expectation. Using a dictionary definition, flexibility can be defined as that which is "adaptable, versatile and variable" (Thompson, 1995). End users expect to be able to derive many energy services from single sources of energy. Electricity provides end users with a number of different energy services including lighting, heating, cooking and the operation of electrical equipment such as kettles, televisions and large-scale computer systems. In the same respect, natural gas is used within buildings mainly for space and water heating but also for cooking applications, industrial processing, etc.

End users expect energy services to be convenient. Convenience can be defined as "serving one's comfort or interests, suitable, free of trouble or difficulty, available or occurring at a suitable time or place" (Thompson, 1995). The concept of "modern convenience" has been explored in detail elsewhere (Warde et al, 1998). Although the concept of convenience is not new, modern convenience is focused on comfort and reducing the effort involved in undertaking routine tasks (Warde et al, 1998). Many products and activities in society are judged in terms of convenience and energy services are no exception to this rule. Energy services provide people with comfort and allow more time to be spent on other activities as opposed to labour-consuming tasks such as washing clothes, cooking and heating the home. Before the availability of electrical and gas-fired space heating systems, homes were heated using coal fires, which was relatively labour intensive. Now, more time can be spent on other activities. Although it is unlikely that end users would go back to having real coal fires, there is a demand for coal-effect gas fires. Coal-effect fires provide comfort and convenience in the home. The advantages of a coal fire i.e. the image or appearance having an open fire and burning coals are provided without the disadvantages of having a real coal fire i.e. labour intensive cleaning and maintenance of the fireplace. By using appliances and equipment, end users enjoy the benefits of energy services whilst having minimum interaction with energy production.

The reliability of energy services is important to end users. The term “reliability” indicates that energy services can "be relied upon" (Thompson, 1995), which suggests that end users expect energy to always be there and be available both now and in the future. Modern energy services are often reliable. A light will come on in a room at the "flick of a switch." Although disconnections of energy supply do occur occasionally, these conditions are only tolerated for short periods of time.

End users also expect a consistency of energy services both now and in the future. Consistency can be defined as being "of sound and consistent character or quality" and "conformity with other or earlier attitudes, practice" (Thompson, 1995). This expectation suggests that any developments or changes in the provision of energy in the future must continue to deliver the same benefits of existing energy services. This implies that any change must be consistent with what end users require, otherwise the change may be rejected.

The acceptability of energy services is an important driver of end user behaviour and attitudes. Acceptability can be defined as "worthy of being accepted, pleasing, welcome, adequate, satisfactory, tolerable" (Thompson, 1995). Although the notion of acceptability varies from person to person, there are three main drivers of acceptability; affordability, quality and cultural values. The acceptability of energy supply can be described as a "balance between the (monetary) cost of receiving a service and the quality of that service" (Consumer Champions, 2003). For some end users, the best service is that which offers the lowest price per unit of energy. In a recent study, the number of domestic consumers switching energy supplier and the motivations behind the move were investigated (MORI, 2001). The research showed that 38% of electricity consumers and 37% of gas consumers changed supplier over a 12 month period. Although price was identified as the main motivation for the change in energy suppliers, other benefits such as dual fuel, whereby consumers can receive electricity and gas from the same company, were also an important driver for switching supplier. For consumers who returned to original suppliers or who did not switch suppliers, better prices, quality of service and trustworthiness were identified as motivations behind consumer behaviour. This indicates that some end users are prepared to pay more for energy provided by a reputable energy utility and energy services which may offer additional benefits such as a better quality service.

However, end users on low incomes cannot always afford energy costs, which leads to fuel poverty. This has a negative impact on the quality of life of people at risk (DTI, 2001b). The acceptability of energy services in terms of different cultural values is emerging as an important factor in consumer behaviour. In recent years, there has been growing interest in the environment and sustainability issues particularly in relation to the negative effects of human activities on the environment. Public awareness of environmental issues such as climate change, resource depletion and waste problems has led some end users to choose energy services which have a lower impact on the environment. Research has shown that some consumers are prepared to pay more for energy produced from alternative or "green" energy sources such as wind power (MORI, 2001). In 2001, ethical spending in the UK had increased with sales of green energy showing the most growth when compared to other sectors including food, household goods and ethical investments (CO-OP, 2002). However, an awareness of environmental issues does not always coincide with the actual purchasing of green products. The low uptake of green energy and other green products and services by domestic consumers has been the focus of extensive research (Pearce, 1990; Berger and Corbin, 1992; Roberts, 1996; Greenprices, 2001; Hobson, 2001; Customer Champions, 2003). Studies which have investigated people's willingness to pay for green products have shown that the consumer's willingness to pay does not always coincide with consumers actually buying the products (Pearce, 1990). There have been many suggestions and possible explanations for the gap between consumer awareness of environment issues and their inconsistent behaviour. It has been noted that consumers often find it difficult to relate local, national and global environmental problems to individual actions (Pearce, 1990). Also, mistrust and cynicism, confusion, the experience of other consumers, the perception of other people's experiences and the prevalence of negative stereotypes associated with "environmentalists" affect the purchase of green products (Pearce, 1990; Berger and Corbin, 1992; Roberts, 1996; Greenprices, 2001; Hobson, 2001; Customer Champions, 2003). It has been suggested that in order to engage consumers, the environmental message needs to be believable and the service must meet consumer expectations of price, convenience, quality and value (Roberts, 1996).

As illustrated, there are a wide range of expectations that end users place on the supply of energy services. These expectations can be summarised as follows:

- Accessibility; all end users can satisfy their energy demand needs,
- Ease of use; all end users are capable of using the delivered energy, it is simple to use,
- Flexibility; energy provides end users with a number of different energy services,
- Convenience; energy services reduce the effort involved in undertaking routine tasks,
- Reliability; energy is always available both now and in the future,
- Consistency; future developments in energy supply will still meet the demands of end users,
- Acceptability; end users choose energy services based on affordability, energy at a price which end users are willing to or can pay; quality, the energy is provided at an acceptable level of service; and acceptability, energy satisfies demand by acceptable (ethical, moral, political, environmental, sustainable) means.

2.3 Energy Suppliers

In addition to end users, energy suppliers are also important stakeholders within the energy system. In most urban areas, energy suppliers will supply end users with electricity and natural gas. However, in a few cities in the UK, district heating suppliers provide heat to buildings via an interconnected network of pipes. As consumer research tends to focus on the end user, there is limited information available from the perspective of the energy supplier. However, with recent changes in the electricity market, it is possible to suggest likely priorities facing electricity companies. The opening up of the electricity market through the Electricity Act of 1989 combined with the New Electricity Trading Agreement (NETA) in 2001 has created a market whereby electricity suppliers are responsible for balancing forecast supply with actual demand. In addition, electricity suppliers must compete with other companies to gain customers whilst trying to keep existing ones. In order to reduce risks, reports have indicated that the quality and reliability of supply, investment into supply infrastructure and the security of supply are important priorities for electricity companies (Ofgem, 2003, 2004c; EA, 2004 and O'Hara, 2003). It is becoming increasingly evident that in order to keep customers and attract new ones, electricity companies must be responsive to consumer expectations. Additionally, electricity companies must comply with the Renewables Obligation by utilising electricity produced from renewable energy sources. In the past, electricity companies regarded electricity as electricity regardless of source. With the introduction of the Renewables Obligation, the source of electricity generation is becoming increasingly important.

Although the 'expectations' of district heating suppliers are less documented and researched, parallels can be drawn. Sheffield is an example of a city with a district heating system. This system is currently operated by a waste management organisation called 'Onyx Sheffield' and is based on the incineration of municipal solid waste (MSW), which is a mixture of non-renewable and renewable/organic wastes. Onyx seeks to provide its customers with an energy service which is reliable, economic and efficient, of a certain quality and which has a minimum impact upon the environment (Onyx, 2004). In order to supply these benefits to its consumers, it is logical to assume that Onyx will need a fuel supply that is continuous and reliable, flexible, cost-effective, of a certain quality with low environmental impacts.

The expectations of energy suppliers are not wholly dissimilar to the expectations of end users. Therefore, the terminology used in the end user demand criteria can be applied here. However, the definitions have been modified to reflect the likely expectations of energy suppliers, as set out below:

- Accessibility - the resource and energy supply is accessible,
- Flexibility - the resource and energy supply is available upon demand,
- Reliability - the resource and energy supply is reliable, both now and in the future, and
- Acceptability - the fuel is supplied at an acceptable price and quality and comes from environmentally acceptable resources.

2.4 Existing Energy Supply

The UK energy system has undergone significant structural change over the last century which has had implications on the accessibility, ease of use, flexibility, convenience, reliability, consistency and acceptability of energy services. The accessibility of energy, particularly electricity and gas supplies, increased due to a number of factors including legislation, post World War Two developments and the discovery of significant natural gas resources. Before the Electricity (Supply) Act 1926, electricity was produced on a small-scale and locally close to the point of demand. Some interconnected distribution networks were developed, providing electricity to a number of industrial applications (Eden and Evans, 1986). Electricity was a new form of energy and high electricity prices combined with limited applications resulted in a low demand for electricity. At this time, the bulk of urban energy needs were met by coal and town gas, a mixture of carbon monoxide and hydrogen, which provided domestic and industrial consumers with energy for lighting, heating and cooking. The Electricity (Supply) Act 1926 established the Central Electricity Generating Board (CEGB) to control and centralise the production of electricity and develop a national grid system to link generation plants to points of demand. Following the Second World War, the national grid system was established which delivered electricity to the vast majority of the population. Electricity was produced in large power stations, away from the point of demand. A national network connected production to demand, therefore increasing the accessibility of electricity throughout the UK. The discovery of large natural gas reserves in the North Sea in the 1960s stimulated investment into converting the gas supply system from town gas to natural gas between 1967 and 1973 (Roberts et al, 1991). During the oil crises of the 1970s, natural gas emerged as a convenient and cheap energy source and, as a result, the use of natural gas has risen rapidly over the past 30 years (DTI, 2000a). A national gas infrastructure was put in place to link gas terminals with demand. As more and more end users had access to electricity and subsequently natural gas, the demand for electrical appliances and equipment increased and domestic coal fires were largely replaced by gas-fired central heating (PIU, 2002).

Electricity and gas are two important energy carriers. The term "energy carriers" refers to a means of carrying or transporting energy from the point of production to the point of consumption. As such, energy carriers provide an important link between the production of energy and its utilisation by end users. In the UK, electricity and gas are commonly-used energy carriers which are distributed to end users via national networks. In some parts of the UK and in other European countries such as Germany, water, air and steam are used as energy carriers within heating and cooling networks. Additionally, work is currently being undertaken in developing hydrogen as a new energy carrier.

Although most end users have access to energy supplies via conventional energy carriers in the UK, some areas are without access to gas supplies. In Great Britain, 20% of domestic households are without access to mains gas (DTI, 2001b). Although the vast majority of these households are in rural areas, there are some urban buildings without access to mains gas. This is due to buildings being constructed without connection to mains gas and for safety reasons (DTI, 2001c). The inaccessibility of mains gas has been identified as one of the key reasons why some households are kept in fuel poverty (DTI, 2001c). A fuel poor household is commonly defined as "one that needs to spend in excess of 10% of household income on fuel use in order to maintain a satisfactory heating regime" (DTI, 2001b). It has been estimated that 29% of households without access to mains gas are in fuel poverty within Great Britain (DTI, 2001b).

In most instances, energy is easy and simple to use as it is delivered to end users in recognisable forms, namely electricity, heat, liquid fuels including petrol and diesel for transportation applications, gaseous fuels such as natural gas and solid fuels such as coal. The safety of the energy supply system adds to the ease of use of energy by the end user. Electricity, for example, is transmitted from large power plants over long distances at high voltages (400 kilo volts (kV) and 275 kV) overground using pylons to distribution companies. The electricity is transformed to lower voltages (132 kV to 230 V) before being distributed to local end users for consumption within buildings (POST, 2001). Within buildings, an internal electrical system distributes electricity to power sockets. End users plug in electrical appliances and equipment which have been especially designed to operate with electricity.

Under current circumstances, energy is flexible as it provides end users with many different energy services. Electricity is the most flexible form of energy as it is used for a wide range of applications ranging from space and water heating to powering electrical appliances. However, despite the flexibility of energy, end users predominately use certain types of energy for certain uses; for example, electricity is used for lighting even though gas lighting is also feasible. In relation to transport, there are a growing number of different fuels which can be used for transportation purposes including petrol, diesel, liquid petroleum gas, electricity and hydrogen. However, the majority of end users continue to use petrol and diesel rather than alternative transport fuels.

The convenience of energy has changed over the last century as the relationship between the production and consumption of energy has changed. In the first half of the twentieth century, energy production was characterised by small-scale energy production which supplied onsite or local energy needs. Individuals, some private companies and Local Authorities owned energy ventures. From the Second World War up to the present day, energy production has been centralised in large power plants, operated by private companies, away from the points of demand. Energy is distributed using national interconnected networks. Electricity and gas meters, cables, pipes, fireplaces, boilers and plumbing are all serviced by specialists. End users purchase energy from energy suppliers and by doing so, pay for the convenience of energy provided by the existing system. There are very few instances whereby individual end users produce energy onsite to meet their energy demands. For the domestic end user, the changes in the energy system have had an enormous impact on the ability to undertake domestic tasks like heating, cooking and cleaning (Warde et al, 1998). Domestic households have moved from using coal for heating to the installation of gas or electric fires. Using coal for domestic fires involved the delivery and storage of coal, people making and maintaining a fire on a daily or regular basis, ash disposal and regular cleaning of the fireplace and chimney. Today, the vast majority of people have gas or electric fires which are turned on or off and the temperature controlled either simply by manual means or automatically via programmers. As such, the interaction of the end user has been reduced to a minimum. End users enjoy the benefits of energy without getting directly involved in energy supplies, generation or transmission.

Energy suppliers also provide end users with consistent and fairly reliable supplies of energy. Even though end users may change energy suppliers, the supply of energy to the end user will continue to be of a consistent quality. Energy supplies are often continuous and uninterrupted with problems only occurring when surges in demand are not anticipated or when the network fails and there are power losses (POST, 2001). In some cases, the National Grid Transco Group, which owns and regulates the electricity network in England and Wales and Great Britain's national gas system, may ask large energy end users to shut down for short periods of time. This allows the supply of energy to domestic end users to continue uninterrupted (POST, 2001). In the longer term, however, the future reliability of the energy system is uncertain due to the reliance on finite resources for energy production. The reliability of energy supply is a focus of concern within the UK and other countries. In the UK, energy sources and suppliers have been identified as ways of diversifying future energy supply (DTI, 2003a).

Energy services are valued by end users in terms of affordability, quality and acceptability. Within the existing energy system, large centralised power plants produce large quantities of energy for a low price, favouring economies of scale. Also, supplying large quantities of energy over long distances to concentrated areas of demand i.e. towns and cities is cheaper than supplying energy to scattered rural locations (Mortimer, Kellett and Grant, 1995). In recent years, the price of energy has been low (PIU, 2002). End users are billed for the quantity of energy consumed over a given period by privately operated energy utilities. Energy suppliers offer a range of services to end users including price tariffs, price reductions, a variety of payment methods and the installation and servicing of meters and pipes. Despite the low price of energy and the variety of payment methods available, there are still issues of fuel poverty within the UK (DTI, 2001b). The quality of the service provided by energy suppliers is important for end users. Considerable research has been undertaken by energy suppliers to identify end user requirements and to ensure that the supplier can provide services which will keep existing consumers and attract new ones.

For some energy suppliers and end users, the health and environmental impacts of the existing energy system are a source of concern. This concern is not unfounded as there are a number of health and environmental impacts or externalities associated with the production of energy. In a recent study, the externalities of electricity production from wind, solar, nuclear, biomass, coal, oil, natural gas and hydroelectric sources were calculated (ExternE, 2003). Quantifiable externalities were measured in terms of public health, occupational health, major accidents, damage to crops, ecosystems and materials, noise, visual impacts and global warming. The results of the study showed that if the external costs of electricity production were included in the price of electricity per kilowatt-hour (kWh), the price of electricity produced from oil and coal would double. Across all European countries, the external costs of electricity production from fossil fuels came out significantly higher than those of renewable energy sources (Rosenbaum, 2002). Additionally, nuclear energy poses problems related to waste disposal and radioactive contamination. The environmental externalities of energy production from nuclear energy sources are not reflected in the price of energy. For some end users, the response to such issues has been to purchase green energy.

2.5 Sustainable Energy Systems

Such qualitative assessment suggests that, whilst the existing energy system currently meets the majority of end user expectations, there are areas of concern for energy suppliers, as summarised in Table 2.1.

Table 2.1 Current Evaluation of the Existing Energy System against Stakeholder Expectations

Stakeholder Expectations	Existing Energy System and End Users	Existing Energy System and Energy Suppliers
Accessibility	●●●	●●
Ease of Use	●●●	-
Flexibility	●●●	●●●
Convenience	●●●	-
Reliability:		
Now	●●	●●
In the future	●	●
Consistency	●●●	-
Acceptability, in terms of:		
Affordability	●●	●●
Quality	●●	●●
Environment	●	●
Sustainability	●	●

Key to symbols:

●	Does not meet expectations
●●	Expectations are partially met
●●●	Meets expectations
-	Not applicable

From the perspective of the end user, the existing energy system performs well in relation to the accessibility, ease of use, convenience, flexibility and reliability of energy services at present. In addition, the existing system offers consistency, affordability and quality. From the perspective of the energy supplier, the existing energy system is not perfect. Issues have been raised concerning the accessibility of resources and the reliability of energy supply, both now and in the future. There are also problems relating to the acceptability of resources and energy production and supply issues, in particular environmental and sustainability concerns. Overall, this assessment has placed doubts on the ability of the existing energy system to produce and supply energy in a sustainable way with minimum impacts on the natural environment whilst continuing to provide end users with reliable energy services in the future.

The sustainability and future reliability of the current energy system has been brought into question. Defined as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs", sustainability in this context seeks to minimise the impacts of energy production, supply and consumption on the environment (WCED, 1987). One of the main challenges facing a sustainable energy system is the heavy reliance of the present system on non-renewable resources. Another key challenge is consumption levels particularly within urban areas. Towns and cities are centres of human activity and, subsequently, energy demand. In order to move towards a sustainable energy system, urban energy demand issues need to be addressed. In addition, an energy system based on renewable energy sources must not only meet stakeholder expectations of reliability and environmental and sustainability concerns, but it must also meet other stakeholder expectations of accessibility, ease of use, convenience, flexibility, consistency, affordability and quality.

It is important to consider whether the adoption of renewable energy technologies as a basis for a sustainable energy system will require fundamental changes to take place on all levels in society. The practical realisation of such a system can be explored by comparing current energy demand with the potential supply of renewable energy sources within the boundary of a town or city. In addition, the prospective carbon dioxide savings by using energy efficiency measures within buildings and renewable energy sources can be estimated. By using Sheffield as a case study example of a city in the UK, an urban energy study can be compiled. Such a case study would provide the basis for establishing the potential contribution of local renewable energy technologies to sustainable urban energy and for the subsequent investigation of barriers facing current and future renewable energy developments.

3. ENERGY USE IN SHEFFIELD

3.1 Urban Energy Demand

Towns and cities are major consumers of energy services. With approximately 40 million people living in urban areas in the UK, there is a constant demand for energy to meet energy needs (DETR, 1998). Most urban areas rely on the importation of energy, the majority of which is produced from fossil fuels, to meet internal energy demands. As such, towns and cities are responsible for large quantities of associated carbon emissions. Very few urban areas utilise local energy resources, in particular low carbon energy resources such as solar energy and wind power, for local energy needs. The challenge that lies ahead is to reduce carbon emissions and make cities sustainable in energy terms. Renewable energy offers a means of achieving sustainability, particularly as they are not finite energy sources. The practicality of utilising local renewable energy resources to meet local energy needs and offset carbon emissions requires further examination. If renewable energy is going to provide the basis for achieving sustainable urban energy systems, it is essential to establish existing energy demands and potential renewable energy supply in a city such as Sheffield.

In order to investigate the potential contribution of local renewable energy supply in meeting local energy needs in Sheffield, current energy demand and associated carbon emissions must be established. This investigation is necessary in order to establish the extent of reliance on fossil fuels and look at how trends influence energy consumption patterns and carbon emissions over a given period. One way to estimate energy use within a city is to undertake a baseline energy assessment using national and local published statistics, as summarised in Section 3.2. In order to do this, the study area must be clearly defined, as demonstrated in Section 3.3. The results of the energy assessment are presented in Section 3.4. This begins by examining overall energy demand and carbon emissions in Sheffield in the year 2000. This is followed by a detailed examination of energy use and carbon emissions within each sector. Changes in energy consumption in Sheffield between 1992 and 2000 are presented in Section 3.5. Future developments in energy demand in Sheffield are examined in Section 3.6. Opportunities for reducing energy use and carbon emissions through the application of energy efficiency measures and local renewable energy sources are identified. This provides the basis for the subsequent examination of ways to reduce energy demand and carbon emissions in Sheffield.

3.2 Baseline Energy Assessment

Within the UK, there are national published statistics available including data on energy consumption, population and employment levels. Local statistical information published by Local Authorities and transport operators amongst others, are also available. This information can be used to produce local energy and carbon assessments. Energy assessments can be used as a basis for predicting future energy trends and carbon emissions, applying relevant energy efficiency measures and assessing the potential contribution of renewable energy sources to urban energy supply. Previous energy assessments of urban areas in the UK include Newcastle-Upon-Tyne (Newcastle City Council, 1992), Sheffield (Grant, 1993, 1994a, 1994b; Grant, Kellett and Mortimer, 1994a, 1994b; Grant et al., 1994c; Kellett, 1993, 1994a, 1994b; Mortimer, 1993, 1995 and Mortimer, Kellett and Grant, 1994) and Conisbrough and Denaby (Grant and Kellett, 2001, 2002a, 2002b, 2002c). By using statistical data, energy assessments provide a quantified assessment of energy use and carbon emissions within a defined area. As energy data can vary in terms of differing area boundaries, data formats and time periods, it is important to clearly establish this study area otherwise data analysis is difficult (Mortimer, Kellett and Grant, 1994).

There are different ways of estimating baseline or current energy use and carbon emissions within a city. A simple approach is to undertaken an approximate estimation using national published statistics to pro rata energy consumption. This pro rata approach takes national data and produces comparable statistics for a local level. This can be undertaken relatively quickly and easily. The use of national statistics allows the study to be replicated easily from city to city although local characteristics and variations are not identified. A more complex approach is to undertake a comprehensive assessment using information collected from local sources such as end users and energy suppliers. As this relies entirely on the collection of local data, it is difficult to execute due to difficulties in obtaining the necessary information as well as time and budget constraints. A compromise between the two approaches is a hybrid assessment which produces detailed energy assessments within the limitations of available resources (Bennett and Newborough, 2001). Due to the limitations of available time and information, a hybrid approach was adopted here based on the methodology adopted for the MIRE study of Sheffield in 1992 (Grant, 1993, 1994a, 1994b; Grant, Kellett and Mortimer, 1994a, 1994b; Grant et al., 1994c; Kellett, 1993, 1994a, 1994b; Mortimer, 1993, 1995 and Mortimer, Kellett and Grant, 1994). Using a hybrid approach allowed local estimations of delivered energy consumption and associated carbon emissions within district of Sheffield by fuel type and sector to be produced using available national and local data. This approach provides a more representative assessment of energy use and carbon emissions in Sheffield than using an approximate approach to pro rata national data on energy consumption. In addition, it provides a detailed picture of energy use by fuel type and sector without undertaking an in-depth and fully comprehensive energy assessment. The accuracy of the hybrid approach lies between the extremes of the comprehensive assessment and the simple approach based entirely on pro rata national statistics. In this context, results from undertaking a comprehensive assessment are likely to be very specific, and subsequently, very accurate whilst those from the pro rata approach cannot be regarded as anything more than indicative.

As part of the hybrid approach, national and local data were used to pro rata energy consumption within Sheffield. National energy consumption ratios were produced in relation to the number of domestic dwellings, numbers employed, the number of vehicles in use and resident population figures, and applied at a local level in Sheffield. Estimations of carbon emissions were produced using carbon coefficients, which show the amount of carbon per unit of energy released upon combustion of the fuel or generation of electricity. By establishing current energy use and carbon emissions within Sheffield, a baseline was set against which other assessments can be measured. Following a preliminary examination of available data sources, the baseline year of the study was set at the year 2000. This was mainly due to the unavailability of later information. For example, the 2001 UK Census was not published at the time of the study. Although the majority of information derives from data for the year 2000, other sources of data are generally current to within two or three years. The figures and percentages presented here are estimations of energy consumption and carbon emissions. In the main text, all numbers have been rounded to the nearest hundred and all percentages to the nearest whole number. However, in order to register the current contribution of renewable energy to delivered energy consumption, relevant percentages are given here to one decimal place. Further information on different approaches for conducting local energy and carbon assessments can be found in Appendix A. The Sheffield Energy Study comprises of three parts, namely a baseline assessment, an energy efficiency assessment and a renewable energy assessment. Detailed information on the baseline assessment of energy consumption and carbon emissions can be found in Appendix B. This includes an examination of the hybrid methodology and carbon coefficients adopted in the Sheffield Energy Study and the results of the baseline assessment. Appendix C contains the methodology use for the energy efficiency assessment and associated results. The methodology and results of the renewable energy assessment are contained in Appendix D.

3.3 Sheffield and the Surrounding Area

3.3.1 Study Area

The study area is defined as the Local Authority district boundary of Sheffield as shown in Figure 3.1. This boundary definition was chosen as national energy data and local statistical information, for example employment figures, are available for this administrative unit. Sheffield is centrally located within the UK and forms one of four Local Authority districts in the County of South Yorkshire, as illustrated in Figure 3.2. With a population of approximately 531,000, Sheffield covers an area of 36,755 hectares (SCC, 1998 and ONS, 2000). Sheffield is situated on seven hills and the confluence of five rivers named the Don, Sheaf, Rivelin, Porter and Loxley (SCC, 1998). The district of Sheffield includes a large built up area which is divided into ten areas of Stocksbridge, Northwest, Chapel Green, Northeast, East End, Southeast, Mosborough, South, Southwest and the City Centre (SCC, 1998). Although Sheffield is largely an urban area, almost one quarter lies within the Peak District National Park. The towns of Barnsley and Doncaster lie to the north. To the east, Sheffield shares a contiguous administrative boundary with Rotherham across the Don Valley. North Nottinghamshire and Sherwood Forest are situated to the south east, the town of Chesterfield to the south and the Peak District National Park to the west. Sheffield's immediate surrounding area includes the contiguous districts of Rotherham, Barnsley, North East Derbyshire, Chesterfield, the High Peak and Derbyshire Dales as shown in Figure 3.3 (Kellett, 1993).

3.3.2 Land Use

The origins of Sheffield date back many centuries. Sheffield developed from a large village surrounded by smaller settlements to a market town and then to a city in 1893. By this time, Sheffield was a major industrial centre for iron, steel, tool and cutlery trades. The completion of the local turnpike road system, the canal and the railway stimulated industrial, commercial and population growth within Sheffield (Hey, 1998).

Figure 3.1 Local Authority District Boundary of Sheffield

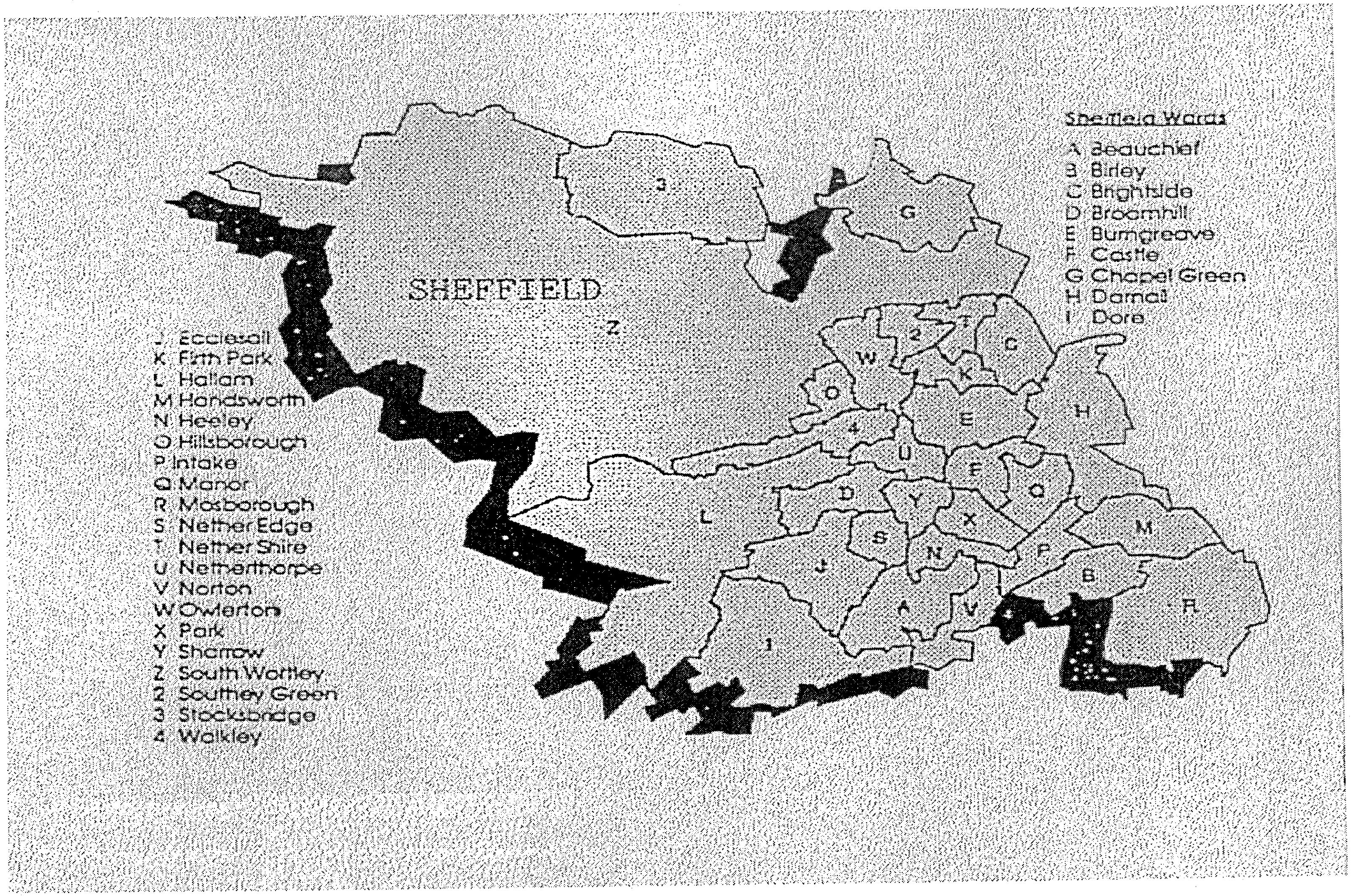


Figure 3.2 Sheffield shown as part of four Local Authority Districts in South Yorkshire

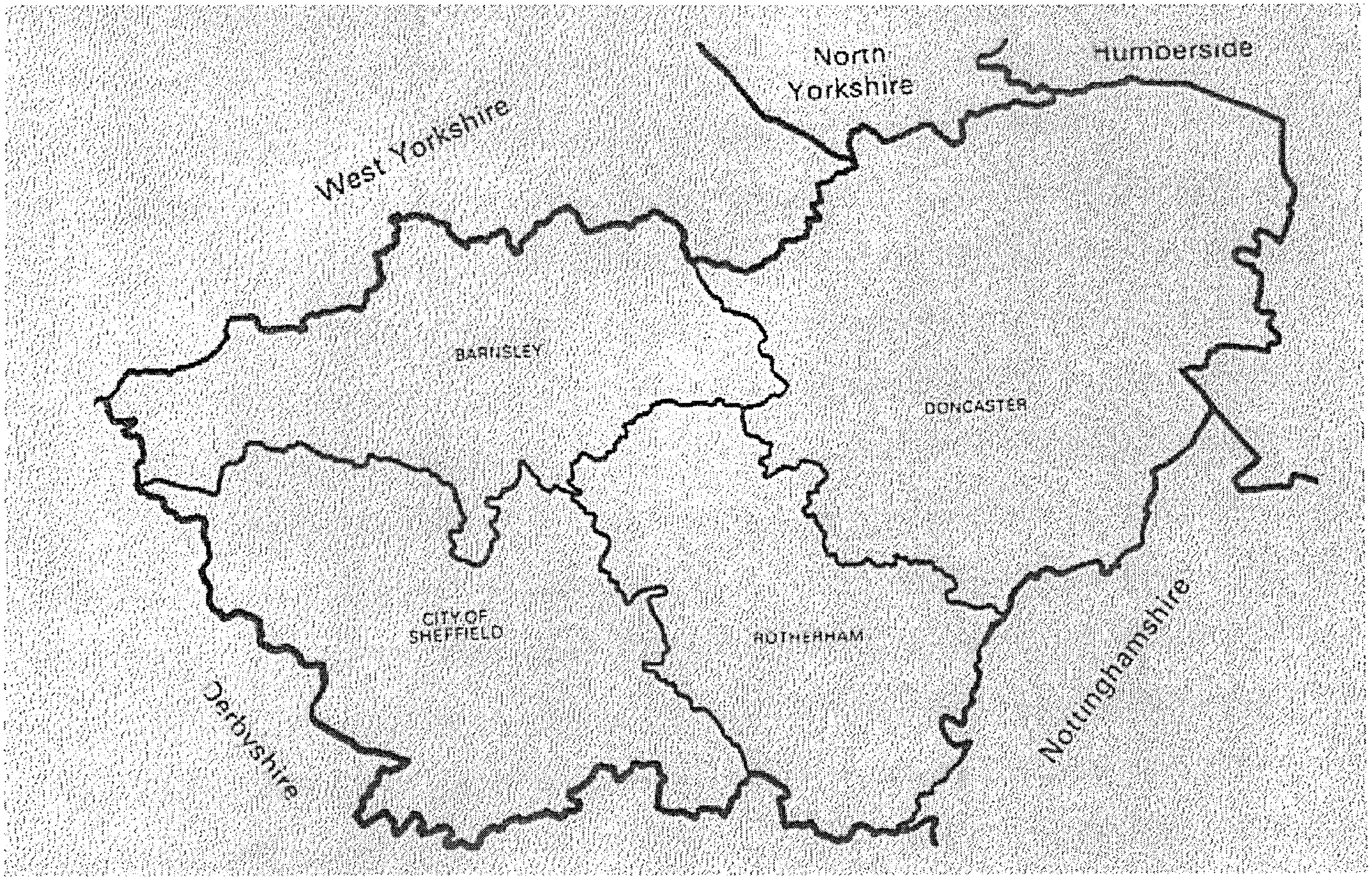
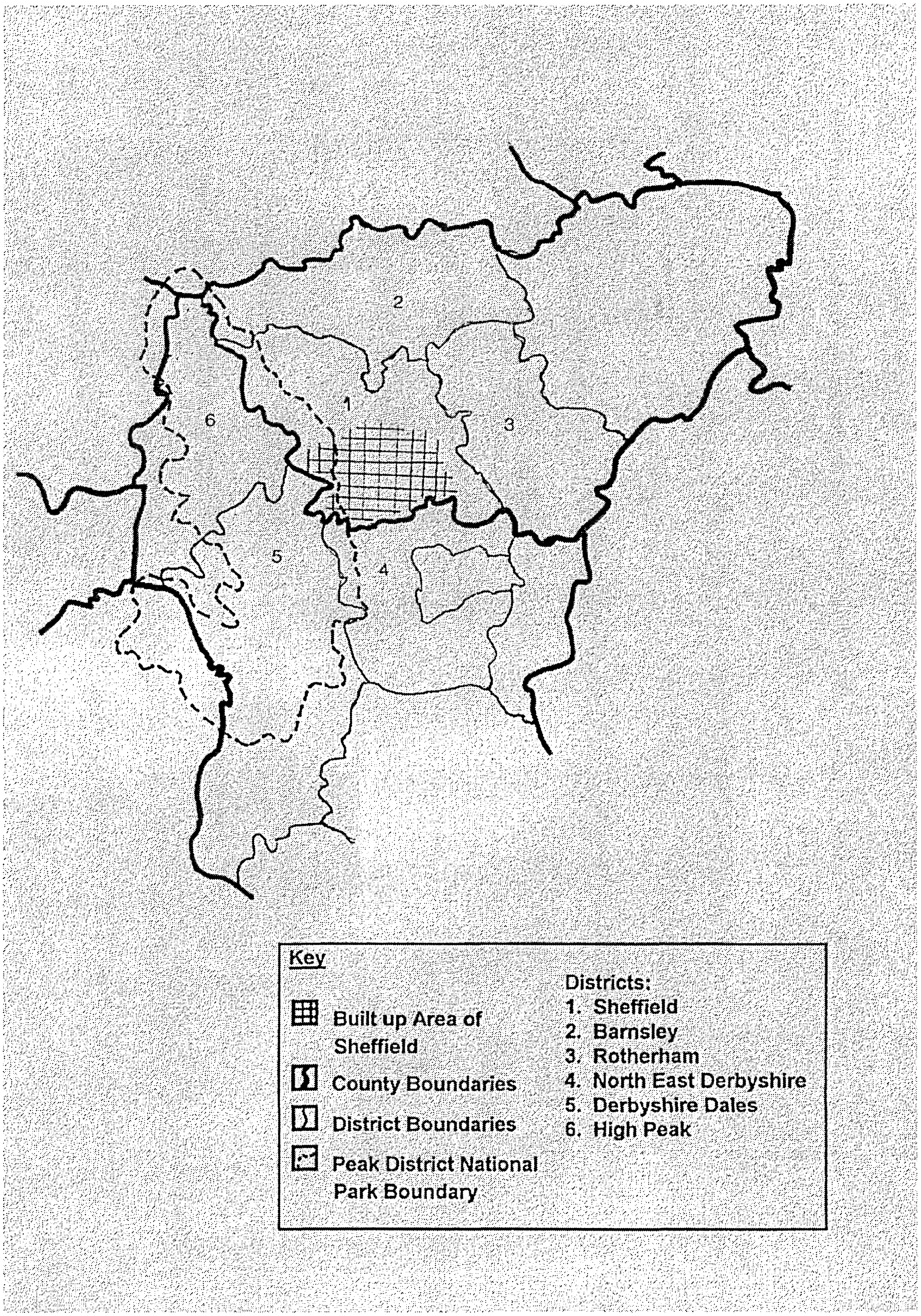


Figure 3.3 Sheffield and the Surrounding Area



Many of the changes made to the built environment in the late nineteenth century remain today. A central commercial core was developed with terraced residential housing erected in the industrial quarters and suburban housing in the west of the city, away from the industrial smog. After the Second World War, city centre slums were cleared and high rise local authority housing at sites such as Park Hill and Gleadless were constructed (Hey, 1998).

A broad mix of housing types remain evident in Sheffield including detached and semi-detached housing, terraces and flats (Grant, 1993). The collapse of the heavy industrial sector during the 1970s and 1980s resulted in major job losses. Consequently, South Yorkshire currently has Objective One status, awarded by the European Commission (SCC, 1998). Despite the industrial changes, Sheffield has remained a major centre for employment, services and education. Sheffield contains two universities, major sporting and cultural facilities and Meadowhall, one of the largest out-of-town shopping complexes in the UK. Other land uses within the district include commercial developments such as offices, industrial sites and public service facilities including schools and health care centres.

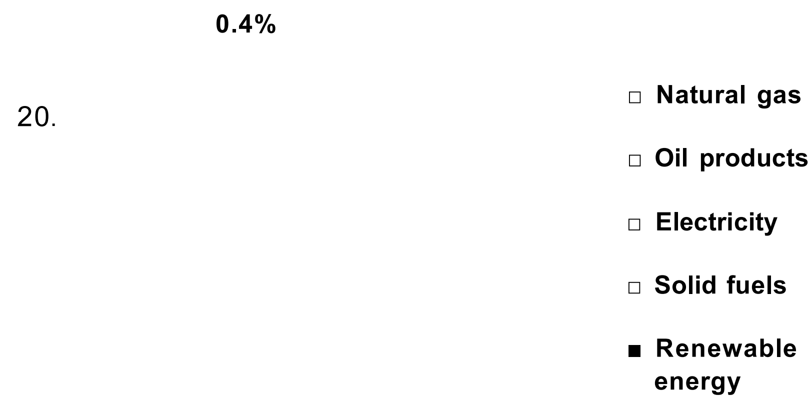
The city centre is the focal point for transport routes. There are a number of trunk roads running through Sheffield in addition to the M1 motorway to the east of the city. Sheffield has railway stations located at Dore, Meadowhall and in the city centre. Supertram, a light rail system, is in operation with three routes totalling 29 kilometres in length (Anon, 2002a). The light rail system operates between Hillsborough, Meadowhall and Halfway and links five park and ride schemes to the city centre (Anon, 2002). Sheffield canal runs between the city centre and Rotherham and a small airport is based at Tinsley. In addition, Sheffield has a district heating network which is supplied by the Bernard Road waste incinerator. A number of buildings including the City Hall, the Crucible and Lyceum theatres, Sheffield University, Sheffield Hallam University and Park Hill flats are connected to this network.

3.4 Energy Assessment Results

3.4.1 Overall Energy Demand and Carbon Emissions

The estimated total delivered energy consumption of Sheffield in 2000 was 52,000 TJ. This delivered energy consumption comprises of five fuel types, namely natural gas, oil products including petroleum, electricity, solid fuels including coal and coke and renewable energy, which has been used to produce renewable or "green" electricity. As shown by Figure 3.4, the three main fuels consumed within Sheffield are natural gas (43%), oil products (32%) and electricity (20%). Smaller amounts of solid fuels are also used in the city. Although the vast majority of all delivered energy comes from fossil fuel sources, a small percentage is supplied by renewable energy sources. This reflects the growing use of renewable energy sources for energy production nationally.

Figure 3.4 Total Delivered Energy Consumption by Fuel Type



The consumption of 52,000 TJ of energy resulted in carbon emissions of approximately 1.1 million tC. The three main fuels consumed within Sheffield are also the three main sources of carbon emissions as illustrated by Figure 3.5. Although natural gas is the main fuel used within Sheffield, it is only the third largest source of carbon emissions. This is because different fuels have different carbon contents. Due to the diverse mixture of fuels used for electricity generation, such as natural gas and coal, the carbon content per unit of electricity is much higher than those of oil products and natural gas. More information on the carbon content of the fuels can be found in Appendix B. All carbon emissions in Sheffield are a result of using fossil fuel-based resources.

Figure 3.5 Total Carbon Emissions by Fuel Type

□ Natural gas

□ Oil products

□ Electricity

□ Solid fuels

Energy consumption in Sheffield varies from sector to sector. The main energy consumers within Sheffield were identified as the domestic sector, the business sector, the industrial sector and the transport sector. For the purposes of this study, the domestic sector refers to residential buildings. The business sector represents business and commercial activities which are very varied and include office employment, education, administration, health care, retail etc. The industrial sector represents manufacturing of all types. Within the transport sector, there are three main modes available within Sheffield, namely road, rail and air. Road transport comprises of private cars and taxis, motorcycles, scooters and mopeds, buses and coaches, light goods vehicles and heavy goods vehicles. Rail transport consists of the national rail network and Supertram, Sheffield's light rail system. At the time of the study, Sheffield had a small airport which operated a limited number of services. Within the UK, energy consumption by sector is often subdivided into thirds, with the business sector, the domestic sector and the transport sector all using approximately one third of total energy supply. As shown by Figure 3.6, Sheffield is not typical of this national picture. The business and industrial sector consumed 42% of total delivered energy, followed by the domestic sector (34%) and the transport sector (24%). Energy consumption by the business and industrial sector is large due to the industrial heritage of Sheffield and the energy-intensive manufacturing industries that still remain in the district. It is likely that the main use for energy within manufacturing industries is process heating, especially due to remaining metalworking and heavy engineering in Sheffield.

Figure 3.6 Total Delivered Energy Consumption by Sector

□ Business and industrial sector

□ Domestic sector

□ Transport sector

As a direct result of the energy consumption by this sector, business and industrial activities are also responsible for the largest amount of carbon emissions in Sheffield as shown in Figure 3.7. This is followed by the domestic sector and the transport sector. In order to provide an insight into energy consumption within each of the sectors in Sheffield, energy use and carbon emissions within the business and industrial sector, the domestic sector and the transport sector are explored in more detail subsequently.

Figure 3.7 Total Carbon Emissions by Sector

□ Business and industrial sector

□ Domestic sector

□ Transport sector

3.4.2 Business and Industrial Sector

Estimations on energy consumption by the business and industrial sector were produced using national energy data (DTI, 2001a) and employment data (National Statistics, 2002a, 2002b and Swain, 2002). Although local energy data for this sector was unavailable due to information confidentiality, local industrial and employment characteristics were drawn out using the SIC system (CSO, 1992). This system classifies economic activities of a similar nature into "industries," for example, manufacturing, construction and commerce. Using the SIC categories, local characteristics were identified and compared with the results of the 1992 MIRE study. A description of the different SIC categories and approach used can be found in Appendix B.

The assessment of energy consumption by the business and industrial sector shows that manufacturing still forms an important part of Sheffield's economic base. Out of the total 21,800 TJ consumed by the business and industrial sector, 63% is consumed by manufacturing industries alone. As Figure 3.8 shows, the two main fuels consumed by industry are natural gas and electricity. These two fuels are the main sources of carbon emissions from this combined sector as illustrated in Figure 3.9. It is also worth noting that industry consumes more solid fuels than any other sector in Sheffield.

Figure 3.8 Industrial Energy Consumption by Fuel Type

□ Natural gas

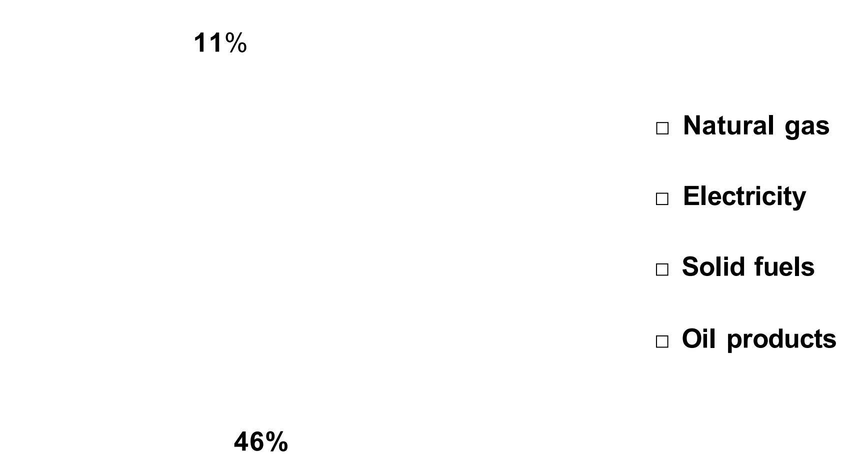
Electricity

□ Oil products

□ Solid fuels

■ Renewable energy

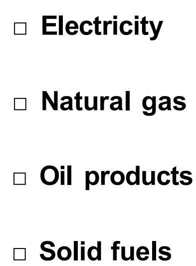
Figure 3.9 Industrial Carbon Emissions by Fuel Type



In addition to manufacturing, there is a diverse range of business activities in Sheffield including health care, education etc. and a wide of service activities. Business activities predominately use natural gas and electricity with some oil products as shown in Figure 3.10. Small amounts of solid fuels and renewable energy are used by business practices in the city. As a result of this energy use, natural gas and electricity are the main sources of carbon emissions for business in Sheffield, as shown in Figure 3.11.

Figure 3.10 Business Energy Consumption by Fuel Type

Figure 3.11 Business Carbon Emissions by Fuel Type



3.4.3 Domestic Sector

Estimations of energy use by the domestic sector have been produced using national domestic energy consumption data (DTI, 2001) and information on the number of dwellings in the UK and Sheffield (Sheffield First, 1999 and ODPM, 2001). Due to the limited availability on the number of households in the UK (Harrison, 2002), this methodology was based upon the number of dwellings. Dwellings can be defined as a unit of accommodation, for example, a house. A household relates to the number of people living at the same address, which can range from one person to a group of people (ODPM, 2002). It is important to note that this methodology does not pick up local variations in energy consumption patterns. For example, Sheffield, once part of a large mining region, is likely to have higher than average of coal consumption which will not be identified by this methodology.

The domestic sector consumes 34% of the total delivered energy consumption within Sheffield. Within this sector, domestic dwellings use the majority of energy for space heating followed by water heating. Lesser amounts of energy are used for lighting, appliances and cooking (DEFRA, 2002 and Zacarias-Farah and Geyer-Allely, 2003). In order to meet these energy needs, the domestic sector primarily uses natural gas followed by electricity as demonstrated in Figure 3.12. As a result of this pattern of energy consumption within this sector, natural gas and electricity are the main sources of carbon emissions as shown in Figure 3.13.

Figure 3.12 Domestic Energy Consumption by Fuel Type

□ Natural gas

□ Electricity

□ Oil products

□ Solid fuels

IB Renewable energy

Figure 3.13 Domestic Carbon Emissions by Fuel Type

□ Natural gas

□ Electricity

□ Oil products

□ Solid fuels

3.4.4 Transport Sector

There are many difficulties when trying to allocate transport energy use within a city. Unlike buildings which are static, each mode of transport available in Sheffield can travel within, through, from and/or to the city from other areas. There are many suggested ways of allocating transport energy consumption within an area including allocating transport energy consumption per person in residence or collectively allocating energy consumption to each mode of transport starting its journey in Sheffield. With such issues in mind, there is a need to allocate energy use and carbon emissions of road, rail and air transport to Sheffield. Road transport energy consumption was estimated based on local vehicle ownership projections for private cars (SYPTE, 2000) and taxis (Boyd, 2002). In the absence of local data, national vehicle ownership projections for motorcycles, mopeds and scooters (CSRB, 2001 and National Statistics, 2000a), buses, coaches, light goods vehicles and heavy goods vehicles (DFT, 2001) were used together with national and local population estimates and national road transport petroleum consumption statistics (DFT, 2001). In order to produce estimations of energy consumption by rail transport in Sheffield, a pro rata approach was adopted based on national and local track length and national rail petroleum consumption statistics (CSRB, 2001 and Williams, 2002). Energy consumption estimations for Supertram were calculated based on the number of passenger kilometres travelled in Sheffield for 2000/2001 and energy consumption estimations per passenger kilometre for light rail systems (Barry et al, 1998 and DFT, 2001).

Estimations of energy consumption of air travel in Sheffield were produced based on domestic flights from Sheffield City Airport. Using flight schedules and an air distance calculator, the total length (kilometres) of outbound flights were calculated. Return flights were not included in the calculations as it was assumed that the refuelling of the aeroplanes formed part of the energy consumption of the destination airport rather than Sheffield City Airport. Private flights and helicopter flights were not included in the assessment due to the unavailability of relevant information. Specific details of the approach used for each of these transport modes can be found in Appendix B.

With such issues in mind, it has been estimated that the transport sector consumed 12,800 TJ of total delivered energy and was responsible for carbon emissions of 257,000 tC for the year 2000. This amounted to 24% of total carbon emissions within Sheffield. Throughout the UK, road transport has been identified as the main source of transport-related carbon emissions (DFT, 2002). This is true in Sheffield as approximately 99% of transport energy consumption can be attributed to road transport. The remaining 1% of energy consumption is primarily used by rail, with a small share being used by air transport. As shown in Figure 3.14, private cars and taxis consume the largest amount of energy (61%) in Sheffield. This is followed by heavy goods vehicles (32%) within the road transport sector. The remaining 7% of delivered energy is consumed by buses and coaches (3%), light goods vehicles (3%) and motorcycles, scooters and mopeds (1%). There are different ways of powering motorised vehicles. The conventional way is to use oil products which mainly include petroleum derivatives such as leaded and unleaded petrol, and diesel. Alternative fuels include liquid petroleum gas (LPG) and electricity. However, due to the limited information available on alternatively powered vehicles in Sheffield, it has been assumed that petrol and diesel are the main fuels used. As Table 3.1 shows, the main fuel consumed by the transport sector was oil products (99.7%) with a significantly lesser amount of electricity (0.3%). Although these numbers are presented to the first decimal place, they are approximate and have been used to illustrate the reliance on oil within the transport sector in Sheffield. All transport modes, with the exception of the Supertram network, consumed petroleum. The national rail network that runs through the district does not include any electrified sections currently. The Supertram network consumes an estimated 37 TJ of electricity and is responsible for approximately 0.5% of carbon emissions in this sector. The remaining carbon emissions are a result of the high levels of oil consumption by transport.

Figure 3.14 Delivered Energy Consumption by Mode of Road Transport

□ Cars and taxis

□ Heavy goods vehicles

□ Buses and coaches

□ Light goods vehicles

H Motorcycles, scooters and mopeds

Table 3.1 Transport Energy Consumption and Carbon Emissions

Fuel type	Energy consumption (%)	Carbon emissions (%)
Oil products	99.7	99.5
Electricity	0.3	0.5
Total	100.0	100.0

3.5 Trends in Energy Consumption

Between 1992 and 2000, the total delivered energy consumption of Sheffield has fallen slightly from 53,500 TJ to 52,000 TJ. Over this period, carbon emissions have fallen by 19% from around 1.4 million tC to 1.1 million tC. The business and industrial sector has remained the largest consumer of energy within the city, followed by the domestic sector and the transport sector. However, there have been changes in the share of energy demand by these sectors as illustrated by Table 3.2.

Table 3.2 Comparison of Energy Consumption by Sector

Sector	Energy Consumption (%)	
	1992	2000
Business and Industrial	48	42
Domestic	31	34
Transport	21	24
Total	100	100

Table 3.2 shows that energy consumption by the business and industrial sector has fallen whilst domestic and transport energy consumption has risen over this period. As Table 3.3 shows, there has been an increase in natural gas, electricity and renewable energy consumption and a fall in the use of solid fuels and oil products. This can be explained by examining changes in fuel mix within each of the sectors in Sheffield. Within each sector, there have been some important changes in fuel mix. For the business and industrial sector, there has been an increase in the use of natural gas, electricity and renewable energy sources. There has been a reduction in the use of oil products whilst the use of solid fuels by this sector has significantly fallen. Within the domestic sector, there has been a slight increase in the use of natural gas, electricity and oil products and a reduction in solid fuel use. This sector consumes more energy from renewable sources than any other sector. Within the transport sector, the fuel mix has changed slightly due to the introduction of the electric Supertram system.

The changes in fuel mix within Sheffield have had a significant impact on carbon emissions. Between 1992 and 2000, total delivered energy consumption has fallen slightly, but total carbon emissions have fallen by 19%. This reflects a number of key national and local trends. Nationally, there has been a move towards the increased use of natural gas for electricity generation as opposed to using solid fuels. Between 1992 and 2000, the use of coal for electricity generation in the UK fell by 25% and oil by 9% whilst the use of natural gas increased by 32% (DTI, 2002b). Additionally, there

Table 3.3 Comparison of Energy Consumption by Fuel Type

Fuel Type	Energy Consumption (%)	
	1992	2000
Natural gas	33	43
Electricity	25	20
Solid fuels	23	4.6
Oil products	19	32
Renewable energy	0	0.4
Total	100	100.0

have been changes in the carbon coefficients of different fuels which have a direct impact upon the calculation of associated carbon emissions. For example, the changes in the fuel mix of electricity generation have resulted in the lowering of the carbon coefficient for electricity. In 1992, the carbon coefficient for electricity was 60 tC/TJ compared with 37.4 tC/TJ in 2000, a reduction of 22.6 tC/TJ (Grant, Kellett and Mortimer, 1994c and Pout et al, 2002). As a result, carbon emissions from electricity consumption have fallen within Sheffield even though electricity consumption has increased. On a local level, Sheffield has experienced a move away from energy intensive manufacturing towards public administration and commerce. This has resulted in less energy-intensive industries and a reduction in the use of solid fuel for applications such as process heating. The combination of national changes in fuel mix and unplanned local economic changes has resulted in lower carbon emissions in Sheffield in 2000 when compared to 1992.

3.6 Future Developments

This quantitative assessment suggests that the energy demand baseline for Sheffield is not static and will change over time. According to national projections of future energy demand (DTI, 2000b), overall energy consumption is forecast to increase at around 1% a year up to 2010. Over the same period, carbon emissions will continue to fall due to the reduction in emissions from electricity generation. From the local baseline comparison, the total delivered energy consumption has fallen by 3% and carbon emissions have fallen by 19% between 1992 and 2000. From 2010 onwards, carbon emissions are expected to rise due to growing emissions from road transport and the domestic sector. As illustrated in Table 3.4, buildings currently consume more than two-thirds of total delivered energy consumption and, as such, are responsible for more than two-thirds of carbon emissions in Sheffield. As such, the built environment offers an opportunity to significantly reduce energy demand and carbon emissions within the district. Although further examination of transport is beyond the scope of this study, it is important to note that in 2000, road transport consumed 99% of the total delivered energy by the transport sector in Sheffield. As energy consumption by road transport is forecast to increase (DFT, 2003), road transport will also emerge as a significant area to address within a city such as Sheffield in the future.

Table 3.4 Energy consumption by the built environment in Sheffield, 2000

Built environment by Sector	Energy Consumption (%)	Total (%)
Domestic	34	
Business and Industry	42	76

The reduction in carbon emissions in Sheffield has happened as a result of changes in the economic base of the district and changes in carbon coefficients, amongst other reasons. These changes have indirectly resulted in lower carbon emissions in Sheffield. If unplanned actions such as these can lead to a significant reduction in carbon emissions, then what would happen if planned reductions were introduced? There are two prominent ways of reducing carbon emissions in buildings. The first is through the introduction of energy efficiency measures. Once buildings are efficient in energy terms, then the remaining energy supply could be met by local renewable energy sources. By using the energy and carbon emissions assessment for Sheffield in the year 2000 as a baseline, it is possible to examine how energy use and carbon emissions can be reduced through the application of energy efficiency measures and increasing local renewable energy supply in a city such as Sheffield.

4. REDUCING CARBON EMISSIONS IN SHEFFIELD

4.1 Current Situation

Over the last ten years, it has been estimated that carbon emissions in Sheffield have fallen by around 19% (Chapter 3). Local and national changes in the economic base of the city, lower carbon contents of fuels and a change in the national fuel mix for electricity generation, have had both a direct and indirect impact on local carbon emissions. Although carbon emissions have fallen, there is still a continued reliance on fossil fuels to meet energy demands in Sheffield. It has been estimated that natural gas, electricity, oil products and solid fuels constitute 99.6% of total delivered energy in Sheffield when compared to 0.4% from renewable energy sources (Chapter 3). This over-reliance on finite fossil fuels in meeting local energy demands is essentially unsustainable. The challenge facing Sheffield is to continue to reduce carbon emissions whilst moving towards the use of more sustainable sources for energy supply, such as renewable energy. Renewable energy offers a way of achieving sustainability as these sources of energy are carbon neutral and cannot be depleted. In order to realise these prospects, the practicality of reducing energy demand and carbon emissions in Sheffield through a planned approach requires further examination. If renewable energy is going to provide the basis for achieving sustainable urban energy systems, it is necessary to look firstly at how current energy demands could be reduced before assessing potential renewable energy availability in a city such as Sheffield.

According to the baseline assessment of Sheffield, buildings accounted for two-thirds of total delivered energy consumption and associated carbon emissions in Sheffield in 2000 (Chapter 3). As such, ways of reducing energy consumption through increased energy efficiency in buildings and substituting the remaining energy demand with local renewable energy supply can be investigated. One way of assessing energy and carbon savings within buildings is to undertake an energy efficiency assessment using national published statistics, as summarised in Section 4.2. In Section 4.3, the results of the energy efficiency assessment are discussed. This provides an illustration of potential energy savings which could be achieved in buildings through the implementation of energy efficiency measures. Further details on energy efficiency assessments and the methods and results of the Sheffield energy efficiency assessment can be found in Appendices A and C, respectively. Once energy savings have been established, a renewable energy assessment can be undertaken to establish local renewable energy supply, as summarised in Section 4.4. In Section 4.5, the results of the renewable energy assessment are compared with the baseline and energy efficiency assessments of Sheffield. This identifies available renewable energy supply, summarises the characteristics of relevant renewable energy technologies and discusses the contribution of renewable energy to existing energy supply. Further details on renewable energy assessments and the detail of the assessment of Sheffield can be found in Appendices A and D, respectively. Based on the findings of the Sheffield energy study, Section 4.6 looks at future energy use in Sheffield. Throughout Chapter 4, energy demand and supply has been presented in terajoules (TJ) and associated carbon emissions in tonnes of carbon (tC). All numbers have been rounded to the nearest hundred and all percentages have been rounded to the nearest whole number. All terms used here are consistent with those laid out and defined in Chapter 3.

4.2 Energy Efficiency Assessment

Energy efficiency assessments are produced for a wide range of purposes including identifying ways of reducing energy consumption and carbon emissions through the introduction of energy efficiency options and providing the basis for implementing energy efficiency plans (Grant and Kellett, 2002a). Energy efficiency options include technical measures, such as replacing light bulbs and improving insulation, and non-technical measures, for example, addressing occupant behaviour (Grant and Kellett, 2002a). There are two general approaches to energy efficiency assessments, namely approximate and comprehensive estimations. Approximate estimations use generalisations and extrapolate energy efficiency data from national statistics. This approach requires less data and is relatively quick and easy to undertake. By using national data, local variations in energy efficiency improvements, which differ from building to building, sector to sector, cannot be identified. Comprehensive estimations are carried out on a case-by-case basis, for example, estimations of energy use, related carbon emissions and energy efficiency opportunities for individual buildings can be produced. Comprehensive estimations are detailed, in-depth and accurate quality assessments which are time consuming and costly. Further details on the different approaches which can be adopted when conducting energy efficiency assessments can be found in Appendix A. For the purpose of this investigation, it was decided that subsequent approximate savings would be adequate. The examination provides an illustration of energy savings which could be achieved in a city such as

Sheffield in order to provide a framework against which any renewable energy contribution could be assessed. In essence, the examination of energy efficiency savings is a prerequisite for looking at ways in which local renewable energy supply might be increased. Potential savings are compared against baseline energy demand and carbon emissions of buildings in Sheffield in 2000, as set out earlier (see Chapter 3). This approach provides a broad indication of potential energy and carbon savings that could be achieved in buildings in Sheffield based on national trends. Detailed information on the approach adopted and the results of the Sheffield energy efficiency assessment can be found in Appendix C.

4.3 Reducing Energy Consumption in Buildings

Buildings in Sheffield consumed an estimated 39,000 TJ of delivered energy in 2000. This energy consumption comprised of natural gas (57%), electricity (27%), oil products (9%), solid fuels (6%) and renewable energy (1%) (Appendix B). This energy consumption resulted in the release of 855,000 tC, the majority of which came from electricity consumption (46%) and natural gas (38%), followed by oil products (9%) and solid fuels (7%) (Appendix B). It has been estimated that by improving energy efficiency, energy consumption and carbon emissions in buildings could be reduced by 14.5% and 14.0%, respectively. As shown by Figures 4.1 and 4.2, this assessment results in a modest energy and carbon savings overall. Energy consumption would be reduced from 39,000 TJ to 33,600 TJ and carbon emissions from 854,500 tC to 735,400 tC.

Figure 4.1 Effects of Energy Efficiency Measures on Energy Consumption of Buildings. Sheffield 2000

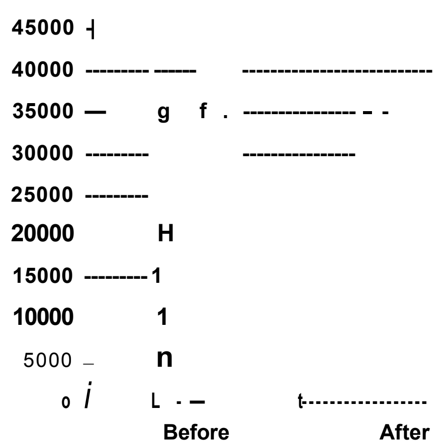
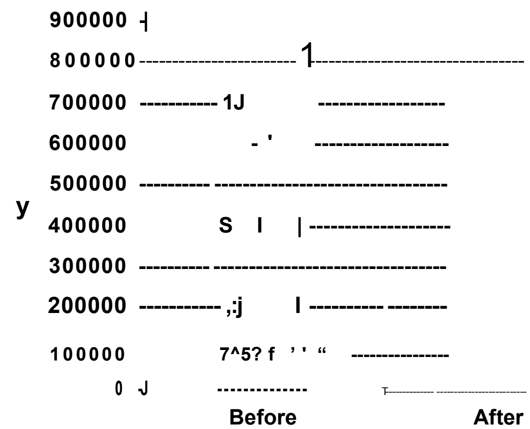


Figure 4.2 Effects of Energy Efficiency Measures on Carbon Emissions of Buildings. Sheffield 2000



Energy and carbon savings as a result of the energy efficiency assessment vary from sector to sector. Figure 4.3 depicts illustrative energy savings which might be achieved over the next 20 years. Within the business sub-sector and the industrial sub-sector, energy savings of 10% may be achieved. Energy savings of 20% could be achieved within the domestic sector. Reducing the energy consumption of buildings lowers associated carbon emissions. By improving energy efficiency, carbon savings could be achieved across all sectors within the next 20 years, as illustrated by Figure 4.4.

Figure 4.3 Effects of Energy Efficiency Measures on the Energy Consumption of Buildings in Sheffield by Sector. 2000

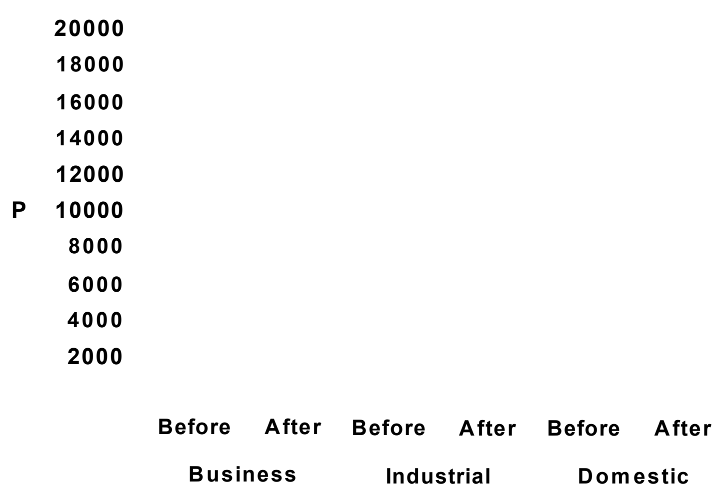
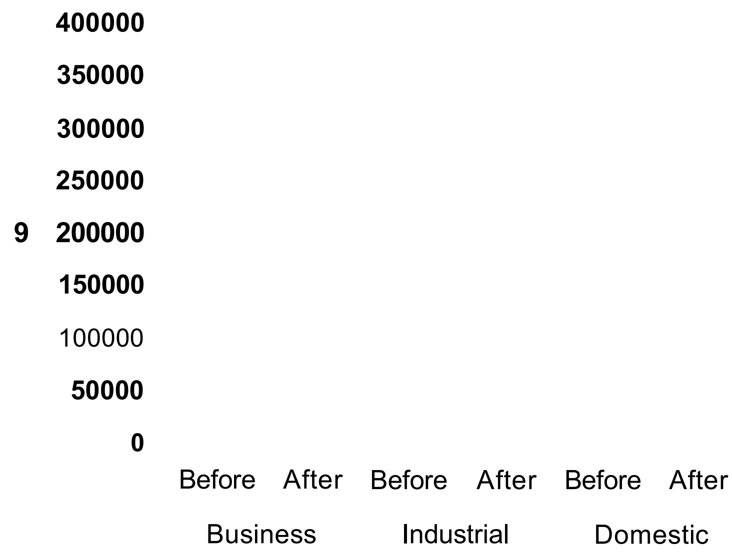


Figure 4.4 Effects of Energy Efficiency Measures on the Carbon Emissions of Buildings in Sheffield bv Sector. 2000



In order to reduce carbon emissions further, local renewable energy supply must be increased. Renewable energy can supply buildings with electricity, heating, cooling and/ or ventilation. In order to target significant areas of energy consumption within buildings with energy efficiency, it is possible to rank relative energy demand in buildings in decreasing order as shown in Table 4.1. The information presented in Table 4.1 has been produced from data contained within Appendix C. A percentage breakdown of overall energy consumption and carbon emissions has been provided to highlight key consumption within buildings in Sheffield. As the shaded area in Table 4.1 shows, natural gas and electricity accounts for 84% of all energy demand and carbon emissions in buildings in Sheffield following energy efficiency measures. Therefore, natural gas and electricity offer a significant opportunity for substitution by available renewable energy supply in Sheffield.

4.4 Renewable Energy Assessment

In order to derive estimations of renewable energy supply in Sheffield, it was necessary to undertake a renewable energy assessment. Renewable energy assessments are produced for a wide range of purposes including identifying local renewable energy sources, estimating economic feasibility of utilising available resources and exploring the possibilities for carbon savings within a defined area. There are two main ways of

Table 4.1 Ranked Energy Demand and Carbon Emissions of Buildings with Energy Efficiency in Sheffield

Sector	Fuel type	Energy Demand		Carbon Emissions		Potential application(s)
		TJ	%	tC	%	
Domestic	Natural Gas	9506	28.3	138782	18.9	Space & water heating, cooking
Industry	Natural Gas	5768	17.2	84211	11.4	Process heating
Business	Natural Gas	3740	11.1	54610	7.4	Space heating
Industry	Electricity	3494	10.4	130679	17.8	Lighting, appliances, machinery
Domestic	Electricity	2874	8.6	107503	14.6	Lights, appliances, cooking, heating
Business	Electricity	2698	8.0	100902	13.7	Lighting, appliances
Industry	Oil products	1496	4.5	29915	4.1	Machinery
Industry	Solid fuels	1449	4.3	37395	5.1	Space & process heating
Domestic	Oil products	968	2.9	19360	2.6	Heating
Business	Oil products	764	2.3	15290	2.1	Heating
Domestic	Solid fuels	578	1.7	14923	2.0	Heating
Industry	Renewable energy	77	0.2	0	0	Electrical-based appliances
Business	Solid fuels	73	0.2	1876	0.3	Heating
Domestic	Renewable energy	70	0.2	0	0	Electrical-based appliances
Business	Renewable energy	34	0.1	0	0	Electrical-based appliances
Total		33590	100	735447	100	

estimating available renewable energy sources, namely approximate and comprehensive assessments. Approximate estimations are essentially scoping studies which provide a broad view of local renewable energy potential. This approach uses available published data and modelling techniques to predict resource availability, assess economic feasibility of potential developments and indicate potential sites for exploiting renewable energy sources. When looking at sites for commercial development, approximate estimations can provide a basis for comprehensive assessments. Comprehensive assessments are essentially site-specific and provide an in-depth, detailed and accurate assessment of available renewable energy at a particular site. Such assessments are feasibility studies undertaken by developers. In order to produce accurate results, more time, effort and cost is involved in collecting accurate data and assessing the technical, economic, non-technical and non-economic issues facing potential development.

In the UK, renewable energy assessments have been produced for regions and local rural and urban areas. One example is the MIRE study where national and local data and modelling techniques were used to produce a quantified renewable energy assessment of Sheffield (Grant, 1993, 1994a, 1994b; Grant, Kellett and Mortimer, 1994a, 1994b, 1995a, 1995b; Grant et al, 1994c; Kellett, 1993, 1994a, 1994b; Mortimer, 1993, 1995 and Mortimer, Kellett and Grant, 1994). As such, a sound basis of information on renewable energy potential is available for Sheffield, the results of which form the basis of the renewable energy assessment of Sheffield in 2000. By using an approximate approach, potential renewable energy supply was compared against the current energy demand of energy efficient buildings in Sheffield. This approach was adopted to provide a general indication of available renewable energy supply and potential carbon savings that could be achieved in Sheffield. Detailed discussion of the MIRE study and renewable energy assessment of Sheffield in 2000 is contained in Appendix D.

4.5 Local Renewable Energy Prospects

In order to determine available renewable energy sources within Sheffield's boundary, an assessment of the resource base, resources and reserves was necessary. The resource base, which can be defined as "the total quantity of energy or power which physically exists in a recognisable form," comprises mainly of solar energy (99%), with smaller contributions from wind power, biomass energy and hydro power, as summarised in Table 4.2.

Table 4.2 Renewable Energy Resources in Sheffield (Grant, Kellett and Mortimer, 1994b)

Renewable Energy Source	Resource Base (TJ/year)	Resources (TJ/year)	Reserves (TJ/year)
Solar energy	2,200,000	8,262	400
Wind power	6,100	2,808	60
Biomass energy	5,000	2,291	0
Small-scale hydro	1,200	90	20
Total	2,212,300	13,451	480

As Table 4.2 shows, a resource base of over 2 million TJ exists. This supply far exceeds current and likely future energy demands in Sheffield. The practical potential of renewable energy supply depends on technical and economic issues. Such considerations make it impossible to exploit the entire resource base. The practical potential of these energy sources depends on the ability and efficiency of renewable technology in collecting and converting renewable energy into useful forms. Resources can be defined as "the part of the resource base which could be developed using existing or modified current technology" (Grant, Kellett and Mortimer, 1994b). By using existing technologies, it has been estimated that available renewable energy resources amount to 13,500 TJ per year. As shown by Table 4.2, this consists of predominately of solar energy (61%), followed by wind power (21%), biomass energy (17%) and small-scale hydro power (1%). Reserves can be defined as "that part of the resources which have proved to exist and which could be exploited under present economic circumstances" (Grant, Kellett and Mortimer, 1994b). Reserves are essentially dynamic in nature due to fluctuating energy prices. It is widely accepted that in an energy market with high energy prices, renewable energy would be able to compete with energy produced from conventional sources. However, energy markets with low energy prices make it uneconomic to exploit renewable sources of energy. In the future, the economic exploitation of reserves may become viable. Although energy prices are beginning to rise, there are uncertainties in relation to how long this will last and to what extent prices will rise. The uncertainty facing the exploitation of reserves is problematic when seeking to assess available renewable energy supply in a city such as Sheffield. Therefore, in order to determine available renewable energy supply in the future, the assessment of resources rather than reserves is most relevant.

In order to provide a brief insight into how renewable energy could meet the most prominent energy demands as laid out in Table 4.1, it is possible to summarise the technologies which could be used to gather and convert renewable energy into useful energy. At present, electricity is likely to be used for a wide range of electrical-based services in buildings whilst the majority of natural gas is likely to be used for space and water heating (DEFRA, 2002). As Table 4.2 shows, solar energy would make the largest contribution to local energy supply. The utilisation of this resource would involve installing passive solar design features and roof and/or façade mounted solar hot water heating or PV panels onto buildings. Sources of biomass which could be utilised include forestry waste, green waste from households and the growth of short rotation coppice. Biomass energy could be utilised to supply buildings with heat in Sheffield. Wind turbines located within the district boundary and the installation of small-scale hydro power schemes would provide renewable electricity for Sheffield.

As illustrated above, Sheffield has potential in terms of available and technically exploitable renewable energy resources. From this assessment, renewable energy resources could provide 38% of the energy demand of energy efficient buildings in Sheffield and displace 50% of associated carbon emissions as shown by Figures 4.5 and 4.6, respectively. Although it is possible to substitute some of the conventional energy supply with renewables, there remains a shortfall in renewable energy supply. In order to meet this supply, short term and long term measures would need to be deployed. One option could be to increase energy efficiency improvements within buildings used within the business and industrial and domestic sectors. In addition, conventional energy sources could continue to be used in the short term, moving towards the importation of renewable energy from surrounding areas in the longer term.

Figure 4.5 Renewable Resource Contributions to the Energy Demand of Buildings in Sheffield

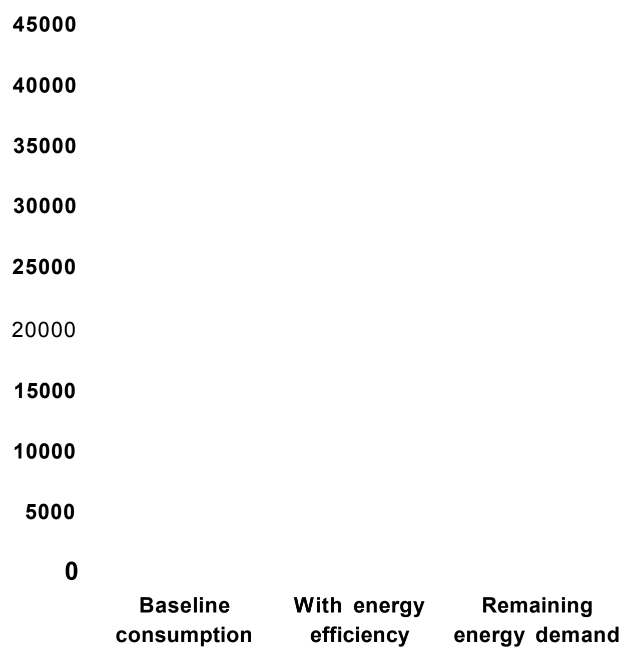
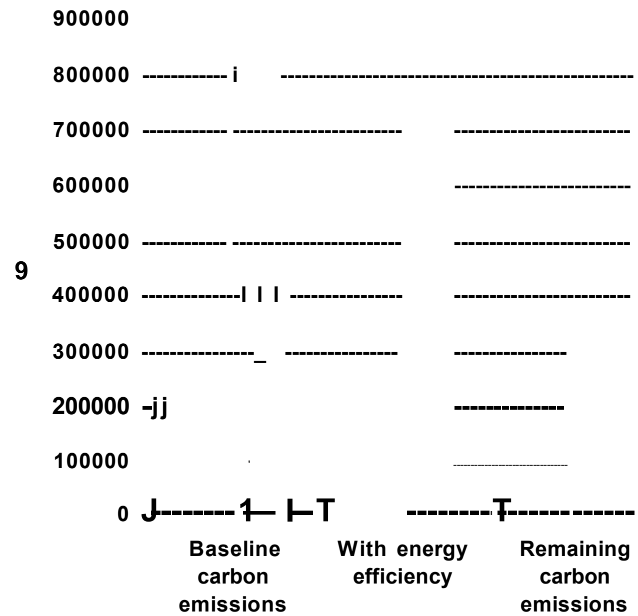


Figure 4.6 Renewable Resource Contributions to Reducing Carbon Emissions in Buildings in Sheffield



As identified in Table 4.1, natural gas and electricity are the two main fuels and sources of carbon emissions in Sheffield. Within buildings, natural gas is likely to be used mainly for heating requirements. Renewable energy technologies, such as solar hot water heating systems and biomass energy, could be utilised to provide stakeholders with heat and/or cooling. By utilising such available resources in Sheffield, natural gas consumption and associated carbon emissions could be reduced by 38% in energy efficient buildings, as shown by Figures 4.7 and 4.8, respectively. Figures 4.7 and 4.8 also show that renewable electricity could meet 90% of the total electricity demand of energy efficient buildings. This would require solar PV panels to be fitted onto the roofs and fagades of business and industrial buildings for use within the buildings or for export to the domestic sector. Exporting solar electricity produced on business and industrial buildings to the domestic sector raises issues concerning supply and demand. Whilst solar electricity is generated during the day, most domestic electricity demand occurs during the evening. One way of matching this supply to demand would be to store the electricity in batteries or to utilise fuel cells. Other electricity demands could be met through the utilisation of wind power and small-scale hydro resources.

Figure 4.7 Renewable Resource Contribution to Reducing Natural Gas and Electricity Usage in Energy Efficient Buildings in Sheffield

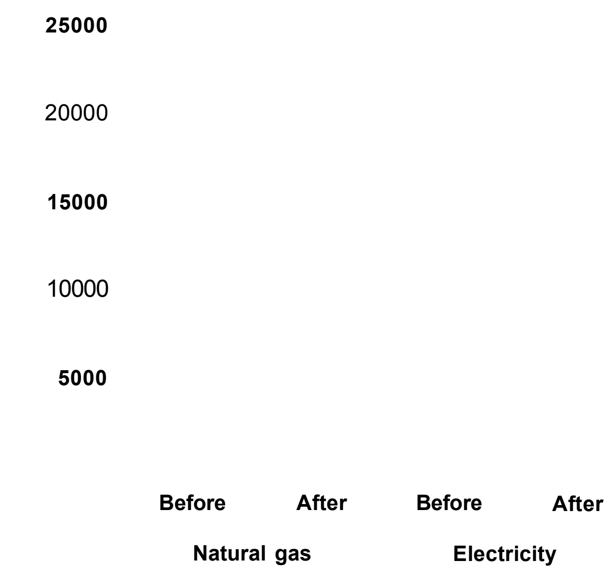
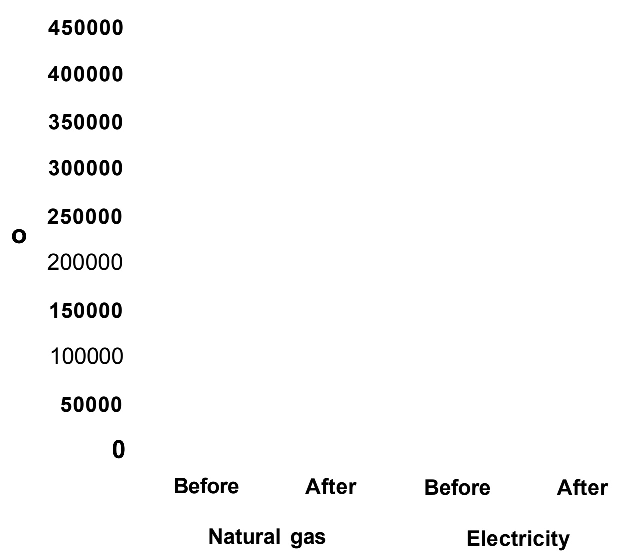


Figure 4.8 Renewable Resource Contributions to Reducing Carbon Emissions Associated with Natural Gas and Electricity Usage in Energy Efficient Buildings in Sheffield



Substituting natural gas and electricity with solar hot water heating systems and renewable electricity has an impact on the energy mix consumed by each sector in Sheffield. As Figures 4.9, 4.10 and 4.11 show, increasing local renewable energy

supply reduces the need for using conventional energy sources within the business sub-sector, industrial sub-sector and domestic sector, respectively. At present, the vast majority of energy consumed by energy efficient buildings comes from fossil fuel sources (Chapter 3). This situation is typical across all sectors in Sheffield. By increasing local renewable energy supply, the need for conventional sources of energy is reduced. By increasing local renewable energy supply, half of the energy demands of the business sub-sector could be met by renewable energy. Additionally, local renewable energy supply could meet one-third of the energy demand of buildings in the industrial sub-sector and one-third of the energy demand of buildings in the domestic sector.

Figure 4.9 Renewable Resource Contributions to the Energy Supply of Energy Efficient Buildings in the Business Sub-sector in Sheffield

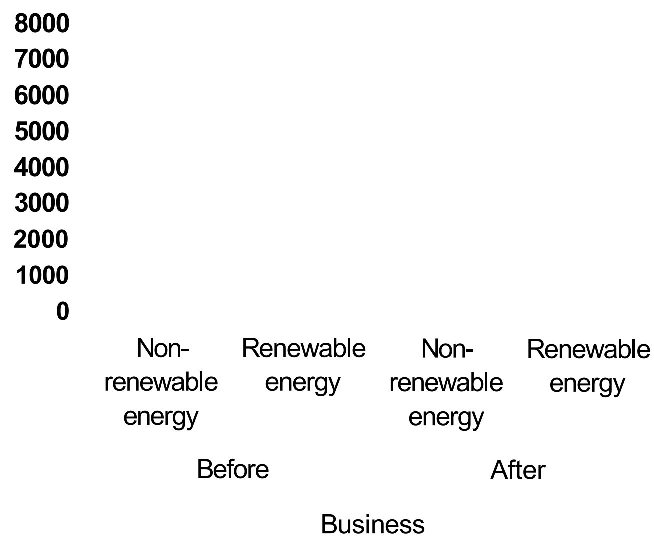


Figure 4.10 Renewable Resource Contributions to the Energy Supply of Energy Efficient Buildings in the Industrial Sub-sector in Sheffield

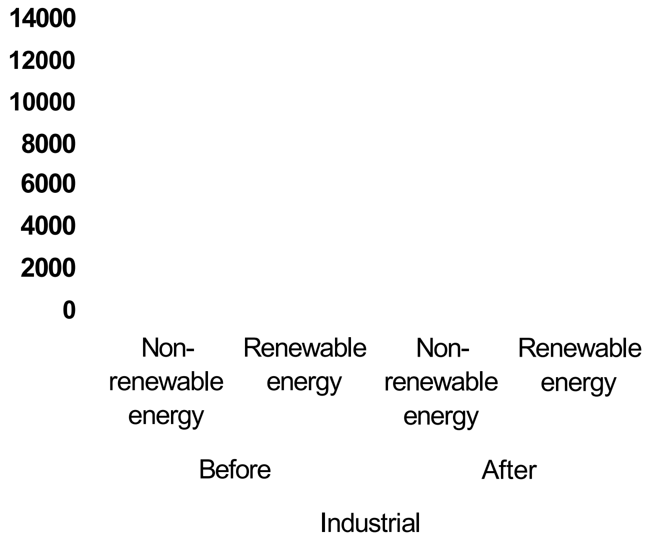
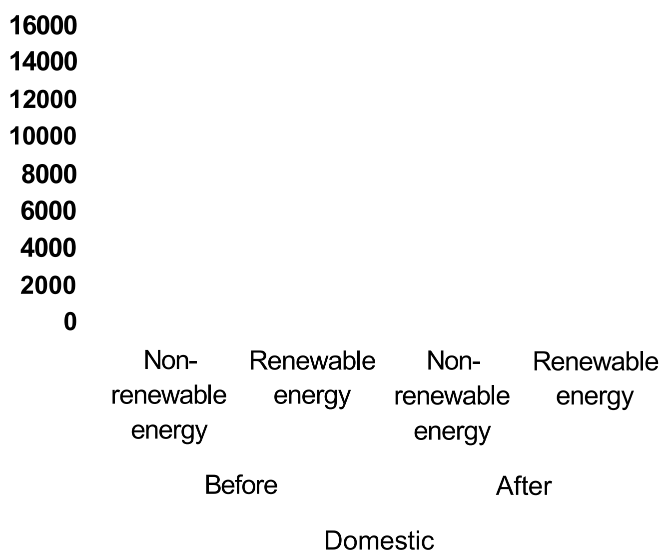
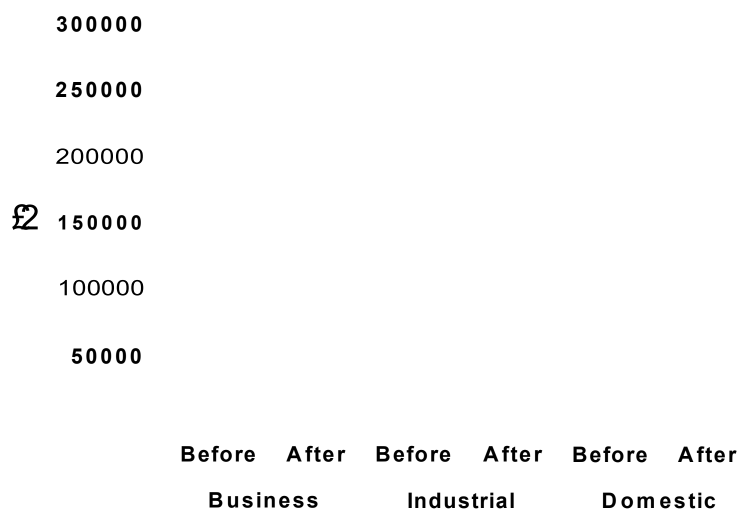


Figure 4.11 Renewable Resource Contributions to the Energy Supply of Energy Efficient Buildings in the Domestic Sector in Sheffield



Perhaps more importantly, substituting renewable energy for natural gas and conventional electricity results in lower carbon emissions across all of the sectors. As Figure 4.12 shows, increasing local renewable energy supply reduces the consumption of fossil fuels, therefore reducing associated carbon emissions. The largest carbon reductions could be achieved within the business sub-sector (65%) followed by the industrial sub-sector (50%) and the domestic (40%).

Figure 4.12 Effects of Energy Efficiency and Renewable Energy Contributions on Carbon Emissions from Buildings in Sheffield



4.6 Future Energy Use in Sheffield

As examined above, the utilisation of local renewable energy resources could meet 38% of the existing energy demands of energy efficient buildings in Sheffield and offset associated carbon emissions by 50%. At present, the energy system in Sheffield relies heavy on fossil fuels imported from outside sources. This system is essentially unsustainable in the longer term as it relies on finite resources which have detrimental environmental impacts, particularly in terms of carbon emissions. By increasing local renewable energy supply, Sheffield's energy system would become more sustainable in the longer term. This examination has shown that the potential exists for lowering energy demand in buildings and increasing local renewable energy supply. Although this potential exists, many actions would be required in order to implement the transition from an energy system based on fossil fuels to a system based on local renewable energy sources. Questions surrounding the current status of renewable energy technologies and their economic feasibility need to be answered. In order to ensure that renewable energy can meet the energy requirements of stakeholders, renewable energy technologies need to be evaluated against the relevant stakeholder demand criteria. As previous renewable energy projects in the UK and other countries have indicated, many obstacles face the deployment of renewable energy in any situation. In particular, it is necessary to establish if these obstacles could be overcome so that energy suppliers can deliver renewable energy to end users in Sheffield. The issues raised here are examined in more detail in the following chapters. The renewable energy technologies applicable to Sheffield are systematically examined and consist of the solar energy technologies of passive solar design (Chapter 5), active solar systems (Chapter 6) and photovoltaics (Chapter 7), wind power (Chapter 8), biomass energy (Chapter 9) and small-scale hydro power (Chapter 10).

5. SOLAR ENERGY TECHNOLOGIES: PASSIVE SOLAR DESIGN

5.1 Solar Energy

Solar radiation varies by geographic location, time of day, time of year and weather conditions such as cloud cover and haze (IEA, 1991). In the UK, solar radiation is not direct but diffuse with long periods of low radiation levels, making it less intense than direct solar radiation (Hill et al, 1995). Solar radiation can be collected and converted into useful forms of energy including space and water heating and electricity. A range of solar technologies are available to capture and convert solar energy into useful energy. Solar energy technologies fall into two broad categories of active and passive solar technologies. Active solar technologies comprise of active solar hot water systems and photovoltaic panels for electricity generation. In contrast, passive solar technologies do not need active components such as solar collectors or pumps to operate. Instead, the design and orientation of the building and the use of building materials are used to provide comfortable internal heating, cooling, lighting and ventilation.

Within Sheffield, solar energy has been identified as the largest single source of renewable energy. Solar energy resources could contribute approximately 8,262 TJ per year. The utilisation of this resource would require installing passive solar design (PSD) features in buildings and using a combination of active solar (hot water) systems on domestic buildings and PV panels on suitable roofs and façades of buildings within the business and industrial sector. Within this Chapter, the practicality of using PSD is examined. The Chapter is split into two key parts. The first part (Sections 5.2 to 5.8) reviews PSD in the broad context of the UK. The basic aspects of PSD are introduced in Section 5.2. The resource considerations (Section 5.3) and applications (Section 5.4) are then discussed. Sections 5.5 and 5.6 explore the technical and economic status of PSD, respectively. The second part of the chapter examines stakeholder expectations of energy services and highlights the differences between PSD and conventional technologies in delivering end users with heating, cooling, ventilation and lighting in buildings. Section 5.7 evaluates PSD against the relevant stakeholder demand criteria, which has been used as a basis for this analysis. From this examination, obstacles facing the practical implementation of PSD in Sheffield are identified. In Section 5.8, additional issues facing PSD are raised. The key challenges facing the widespread realisation of PSD in Sheffield are summarised in Section 5.9.

5.2 Basic Aspects

Buildings provide protection from weather conditions and variations in temperature. Heating or cooling may be required to counteract external conditions to produce a comfortable internal environment for the occupants of the building. Additionally, the availability of light and quality of the indoor air has an influence on the level of comfort. Before the development of mechanical space heating/cooling systems powered by fossil fuels, building design techniques were used to produce comfortable internal living conditions (Santamouris and Asimakopolous, 1996). In Southern dry climates in particular, large openings in buildings allowed air movement and provided a source of daylight. Shading provided protection from direct solar gain and light coloured surfaces reflected the sunlight, reducing the amount of heat entering the building (Santamouris and Asimakopolous, 1996). This design technique is called PSD.

Through the use of PSD, the solar gain of buildings is enhanced and the artificial energy needs of buildings are reduced. The structural design of buildings and the building materials used can be arranged to heat, cool or light the building without the need to rely on active components such as solar collectors, fans or pumps (IEA, 1991). By increasing the thermal mass of walls, floors and ceilings, heat can be absorbed during the day and radiated out at night (Anon, 2000a). High thermal masses and good insulation can also keep the building cool during the day with ventilation cooling the building at night (ICLEI, 2000a). Increasing the thermal mass of the building materials provides a means of heat storage within the building.

Using traditional passive solar technologies, such as Trombe walls and roof pond systems, can provide additional storage. A Trombe wall is a wall, which is blackened and glazed on its exterior (Gan, 1998). Using solar radiation to power the effect, the wall allows air to move in a controlled way through the opening and closing of vents (Ashley et al, 1996). Roof ponds store water in a large container covered by glazing. The warm water in the pond heats the space below (Anon, 2000a). To help ensure that the supply of passive heat is reliable, a conventional heating source can provide back-up heating should a shortfall in supply occur. The type of PSD techniques used varies from application to application. The diversity of PSD allows the occupiers needs, the characteristics of the building and the resources available to be matched resulting in enhancing the passive heating, cooling, ventilation and/or lighting of the building.

5.3 Resource Considerations

For passive solar features to reach their full potential in the UK, the optimum orientation of buildings is north-south facing. Glazed areas must face south or within 30 degrees of south, and have glazing or shutters to minimise heat loss at night (ICLEI, 2001a). Overshadowing can reduce the performance of the passive solar system as the level of heat and light entering the building and the ventilation flows are reduced (Littlefair, 1998). To optimise PSD, the areas of the building that require more heat and/or light should be south facing, with other areas being situated on the north-side of the building. PSD maximises solar energy gain of buildings. The opportunity to maximise solar energy gain is influenced by the number of opportunities to use PSD features in buildings. PSD can be incorporated into the design of new buildings or added to existing buildings when refurbished. Refurbishing existing buildings with PSD features can be difficult as the orientation of the building, the type and position of surrounding objects and the building materials are already in place. New buildings offer more flexibility in the positioning of the building, the size and position of the glazed areas, the density of the buildings and the building materials used (NEF Renewables, 2001). The opportunity to integrated passive solar features into the buildings depends on the rate of new development and the take-up of PSD features in new build designs. Within the UK, the rate of replacement of buildings is between 1-2% per year. This means that it would take a minimum of 50 years to replace existing buildings with PSD and other solar energy technologies (Ashley et al, 1996). As such, a more realistic alternative would be to retrofit existing buildings with PSD features.

5.4 Applications

Most buildings in the UK utilise passive solar energy to some extent through windows, conservatories and larger glazed areas such as atria. Windows allow daylight and heat to enter existing buildings whilst allowing occupants to view outside. Beyond this largely unplanned use of passive solar energy, PSD has been used in combination with energy efficiency measures, in particular good insulation measures, to reduce energy costs in housing, as in, for example, the Autonomous House at Southwell, Nottinghamshire (ETSU, 1999). Other demonstration projects and studies have shown that low-energy and 'zero energy' housing is feasible with energy savings being made over a given period. The number of buildings specifically designed to use passive solar energy in the UK is estimated at a few thousand (ETSU, 1999). Other features that can be used in buildings in the urban environment include glazed balconies.

5.5 Technical Status

Passive solar heating technologies are largely mature whilst passive solar cooling technologies are less developed. There is a drive to improve passive solar technologies and reduce technology costs overall. Technological improvements are being developed to improve building designs, the air tightness of buildings, the yields of glazed areas and the building materials used. Additionally, work is being undertaken to minimise heat loss and maximise energy savings. A number of advances have been made in glazing. Using transparent insulation in windows reduces the transmission losses of solar gain (ETSU, 1999). Triple glazed windows with special coatings can increase the insulation value of the window. This allows the windows to be net producers of heat, even when facing north in the winter (ICLEI, 2000a). Improvements in the thermal storage of glazed areas are being developed combined with improvements in passive solar energy storage facilities. Advances have been made in improving the thermal storage capacity of building materials. In particular, the thermal storage of wallboards can be increased by impregnating the wallboards with phase change materials (PCM). With PCM, heat is stored when the material changes its chemical composition unlike other building materials, such as bricks, that store heat as the temperature of the material increases. Work is being directed towards reducing high investment costs associated with some applications by reducing technology costs through technological innovation (ETSU, 1999). Research and demonstration projects are exploring the adaptability of PSD technologies for existing and new buildings. Whilst achieving technical and economic improvements, it is hoped that the thermal and visual comfort of buildings will be maintained and improved (Voss, 2000).

5.6 Economic Status

There is a close relationship between the complexity of the PSD, the components used and the capital investment costs required. Whilst some features can be introduced at little or no extra cost, other features, such as high performance glazing or atria, can significantly increase costs (IEA, 1991). However, the amenity value of atria may outweigh their costs (ETSU, 1999). In general terms, it is more economic to incorporate PSD into new buildings since retrofitting existing buildings can be expensive. When retrofitting existing buildings, the fabric and structure of the building may have to be significantly altered. Cost savings can be gained by avoiding rooms and/or buildings with air conditioning units or additional heating systems (ETSU, 1999).

5.7 Meeting Stakeholder Expectations

5.7.1 PSD and End Users

If, in order to reduce local carbon emissions, there is a move towards the wider use of PSD in Sheffield, this will have implications for the relationship between end users and the production, supply and use of energy in buildings. End users have different relationships with buildings depending on if they own and/or occupy the building. The relationship of the occupier to the building is important when decisions are made on how the building will be heated, cooled, lit and ventilated. At present within the UK, buildings and energy provision are viewed as separate entities. Traditionally, energy has been delivered or supplied to buildings from external sources rather than using natural energy flows and building design/materials to enhance the heating, cooling, lighting and ventilation of a building. Unlike conventional energy systems, the use of PSD turns the building into an energy system. This has implications on how the occupier interacts with the building and its energy systems. Interaction between the occupier and the buildings is important as, once in place, it is important that the energy from PSD substitutes existing energy supply rather than increases energy consumption. In addition to these issues, end users expect a certain level of energy service. The success of any new technology or energy service is dependent on its ability to meet existing end user expectations of accessibility, ease of use, flexibility, convenience, reliability, consistency and acceptability, as identified in Chapter 2. The ability of PSD to meet these expectations will influence the success of the practical deployment of PSD within buildings in Sheffield, as examined below.

5.7.2 Accessibility

The extent to which PSD is accessible by all end users is variable. Due to differing occupier needs and the characteristics of the buildings, PSD applications may be suitable for some buildings and unsuitable for others. New build increases the accessibility of PSD as features can be integrated into the building's design and construction. The other option is retrofit in which PSD applications are building-specific. Another option would be to incorporate PSD features into routine building refurbishments, for example, extensions to households and roof replacements. Whilst it may be difficult to encourage end users to opt to change their building solely for PSD purposes, combining PSD with other building work may be a more viable option.

Although it is easier and often cheaper to install PSD into new buildings, the replacement rate of new build is generally low in the UK. For a district such as Sheffield, installing PSD into new build would mean that it might take between 50-100 years to equip each building in Sheffield with PSD features. Taking these time scales into account raises a number of significant questions, namely, is this viable? Is new build the answer or should Sheffield be concentrating on incorporating PSD into routine building refurbishments? If the latter option is chosen, can it be done and, if so, how? Although PSD is a mature technology, features such as Trombe walls and roof ponds are unheard-of by the vast majority of end users in the UK, and as such, are not common features of buildings. Therefore, in order to instigate its wider use, numerous actions will be necessary over the longer term.

5.7.3 Ease of Use

There are two issues surrounding the ease of use of PSD, namely, choosing PSD features as a way of heating and cooling a building for example, and the operation of PSD features within buildings. The necessary infrastructure required to sell PSD to end users and install PSD features within buildings does not exist. There are few systems in place to make people aware of PSD opportunities, to provide information and guidance to end users. PSD features are not readily available for end users to view and there are few trained specialists to install and/or maintain the systems. Also, there is limited financial support in the form of grants, etc. In many respects, a "chicken and egg" situation exists as there is no supply of PSD features due to the lack of demand and, as such, there are very few products available for end users to purchase in shops etc. This situation needs to be overcome for PSD to be more widely deployed in the UK.

Once PSD features are installed in buildings, end users may perceive PSD as difficult to use as they are unfamiliar with the technology and the way it works. Whilst conservatories and atria are quite common place, other PSD features, such as roof ponds or Trombe walls, are not widely utilised. There are very few examples of such features in the UK except for demonstration projects. As PSD features do not conform with conventional energy systems within buildings, unfamiliarity may be a problem. Unfamiliarity is likely to impact upon end user's perceptions of PSD as being easy and simple to use. As with any new technology, end users will have to learn how to use the technology in order to use it to its greatest potential. In addition, mis-use of PSD technologies could lead to energy wastage and an increase in energy consumption.

One example of this is heating conservatories in winter. This results in more energy being used to heat the conservatory in addition to heat being lost through the un-insulated glass panels.

5.7.4 Flexibility

In general, PSD is flexible as it can provide end users with a number of different energy services. At present, these energy services are provided by the existing energy system and conventional energy technologies such as fireplaces, radiators, fans and electric lighting systems as opposed to utilising the building's orientation, structure and materials to create an energy system. When looking at individual buildings, the flexibility of PSD is brought into question. In new build, PSD can meet a range of energy requirements as the orientation and building materials can be specifically chosen to take full advantage of PSD. However, in retrofit schemes, the extent to which PSD is flexible enough to meet end user's energy needs is questionable. With the orientation of the building pre-determined, the only alternative is to change buildings materials inside and outside the building. Although this can enhance the buildings natural heating, cooling, lighting and ventilation to some extent, its energy provision may be limited.

5.7.5 Convenience

Adding PSD to existing buildings, as with any other type of building work, is rarely regarded as convenient. Although changes to buildings are planned, inconveniences occur to the remaining occupants in the building during the time of retrofit. However, if PSD is incorporated into existing refurbishment schemes, such as building extensions, it could be argued that the inconvenience is reduced. This integration allows all the necessary changes to be made in a single operation rather over separate periods of construction work. With new build, no inconvenience would arise as the incorporation of PSD would fit in with the overall construction of the building.

It is difficult to determine the extent to which the supply of heating, cooling, lighting and ventilation from PSD will be seen as convenient by end users once these measures are in place. Although PSD can supply important energy services, the ways in which it does this is different from conventional energy sources. As previously mentioned, changing the materials of a building and/or addition features such as sun pipes or Trombe walls, turns the building into an energy system. Some features operate independently of occupant, such as sun pipes, whereas other features, like Trombe walls, require vents to be opened or closed. This could be done manually or using intelligent system controls, set on timers for example. It is fair to say that although such features are different to conventional energy technologies, conventional features such as boilers and radiators also require some level of human interaction, for example, when changing the internal comfort of a building. As with all new technologies, occupants would need to learn how to use PSD features. Over time, as occupiers become more familiar with PSD and learn how to view the building as an energy system in its own right, the convenience of PSD features are likely to increase.

5.7.6 Reliability

As previously examined, solar energy is a reliable energy supply as it is naturally replenished as it is consumed, unlike conventional energy sources (IEE, 1994). In seeking to reduce local carbon emissions associated with energy use, solar energy is carbon neutral, making it suitable for sustainable energy developments. Although solar energy supply is reliable, questions surround the reliability of PSD technologies and their installation and maintenance. When introducing PSD into retrofit schemes, the structure and/or external appearance of the building will be changed. Therefore, it is important that the PSD technologies and the materials used are reliable and perform in accordance with end user requirements. This raises the issue of the need for PSD materials, product and installation guarantees, in order to assure consumers that PSD technologies meet their energy requirements.

On another level, architects and builders would need to guarantee that the retrofit incorporating PSD feature will perform correctly. Whilst the performance of the technology may be guaranteed, poor retrofit design and workmanship could offset any advantages gained by the introduction of PSD. For example, it may be possible to guarantee the performance of a Trombe wall, but if the wall was installed on the north-side of a building in Sheffield, the wall would fail to work as a PSD system. Therefore, the product, its installation and performance are intrinsically linked. In addition to this, occupier interactions with PSD systems are also important in relation to reliability issues. Studies have shown that whilst there is current growth in demand for installing conservatories, subsequent mis-use of the conservatory can lead to a net-increase in energy consumption (Oreszczyn, 1993). Whilst product designers assume how occupiers will interact with products, in reality, this is not often the case. Although the product and its installation could be guaranteed, occupier use may also affect the performance of the system. Failure to recognise mis-management of the system could lead to end users labelling PSD as unreliable and inefficient.

5.7.7 Consistency

End users expect a consistent energy service, both now and in the future, which suggests that any changes in energy provision must continue to deliver the same benefits of existing energy services. PSD can supply end users with important energy services, which are consistent with current energy demands. To varying degrees, PSD can provide end users with heating, cooling, lighting and ventilation in buildings. However, in terms of energy provision, PSD is not consistent with traditional methods of heating, cooling, lighting and ventilating buildings. This inconsistency may act as a barrier to the wider use of PSD in buildings in the UK.

5.7.8 Acceptability

End users choose energy services based on affordability, quality and/or wider ethical, environmental and sustainability concerns. It is difficult to quantify the cost of PSD as its application is site-specific. Although solar energy is essentially "free", the installation of PSD into existing buildings has implications in relation to initial investment and payback periods. This is one of the reasons why integrating PSD into routine refurbishment schemes is important as, although extra costs may be incurred, overall costs may be lower than adding PSD to the building at a later date. This latter option may be very expensive. At present, there are no grants available to help offset the installation of PSD features into existing or new buildings. As such, the cheapest option facing PSD is to install the features into new build.

Within the existing energy system, the quality of service is a key motivation for end users switching suppliers. The use of PSD moves away from conventional energy provision. The building becomes more pro-active in providing heating, cooling, lighting and ventilation to the buildings occupants, therefore reducing the need for service provision by energy suppliers. Additionally, end user expectations of quality emphasises the need to ensure quality products, installation, operation and maintenance as a way of motivating end users to make decisions regarding the adoption of PSD technologies.

The acceptability of energy is becoming increasingly important in terms of the immediate and long term impacts of energy production on the environment and the future sustainability of energy sources. Using natural energy flows such as solar energy reduces the need to rely on finite and harmful fossil fuel resources to meet energy needs. In addition, the utilisation of solar energy decouples end users from future fossil fuel energy price rises. The use of solar energy through PSD is site-specific, which means that any beneficial or adverse impacts from using this technology will have to be addressed within the local area. This contrasts with the existing system whereby any environmental impacts from large-scale energy production often occur away from the point of consumption. In the case of PSD, the local community and city as a whole will become responsible for energy production and managing its environmental impacts.

5.8 Additional Issues

5.8.1 Perception of Risk

People's perceptions often act as a barrier to the success of a new product or technology. It is these perceptions, whether accurate or not, which influence people's views and acceptance of change. Within the building industry, particularly in relation to domestic housing, there is a perception of risk associated with unconventional buildings. It has been suggested that housing incorporating PSD features will not sell due to the 'futuristic' appearance of the building and higher construction costs (DTI, 2001d). In a recent study, ways of introducing PSD features into three standard Barrett house designs were examined (DTI, 2001d). The study found that passive solar features could be successfully integrated into housing design with no major changes in the appearance, cost and marketability of the building (DTI, 2001d). This highlights that the lack of knowledge, information or perhaps inclination within the building industry to utilise PSD features within buildings.

In addition to the building industry, the owners of existing domestic and non-domestic buildings may also perceive cost and marketability risks when seeking to retrofit the building utilising PSD or selling the building. Such perceptions can act as a barrier to PSD in particular and towards changing from the existing energy system towards on based on renewable energy in general. People's resistance to change can occur for a number of reasons including self-interest, fear of the unknown, different perceptions, suspicion and conservatism (Anon, 2003). In order for PSD to become more widely used, it is important that such issues are understood and overcome.

5.8.2 Planning Issues

One key issue facing the wider use of PSD features in buildings is whether or not the changes are accepted by the local community. This issue raises questions, namely, is PSD something that people want and are prepared to see buildings altered to incorporate PSD? Are these features something that people would like to see on buildings in Sheffield? The planning system has an important role to play in determining whether or not PSD developments can take place. To date, there are very few examples of the incorporation of PSD into retrofit to act as precedent for planning decisions. This lack of precedent may cause problems for PSD planning applications. Any uncertainty surrounding the ability to gain planning permission for PSD is likely to breed uncertainty amongst planners, developers and other decision-makers. In turn, PSD may be labelled as a difficult option, therefore dissuading end users from investing in PSD developments.

It is difficult to ascertain the problems facing PSD in general as planning permission applications will take place on a building-by-building basis. However, given existing planning regulations, it is likely that where the entire character of a building may be changed through the addition of passive solar technologies such as glazing, external sunshades and Trombe walls, planning permission will be required (ODPM, 1995). For other passive solar features, such as conservatories, the size and sitting of the feature will determine the need for planning permission. It is unlikely that the addition of semi-transparent windows will require planning permission. Additionally, local variations such as area and building designation will influence the need for planning permission.

When considering planning applications, interpretation of existing planning legislation and policy by local planning authorities may vary due to varying degrees of policy guidance and local experience of active solar systems. Planning Policy Guidance (PPG) note 22 on renewable energy sets out the Government's national stance on renewable energy developments. This document has been criticised as lacking in clarity, a clear focus and policy direction (Gill, 2004 and Kelly and Evans, 2004). However, a new proposed planning policy statement (PPS) on renewable energy is set to supersede PPG22 (ODPM, 2003a). Planning Policy Statement 22 (PPS22) on renewable energy seeks to provide more guidance and support for renewable energy developments. The document advises Local Authorities to promote and encourage renewable energy developments rather than limit them. The revisions and updates have been welcomed although a companion guide to PPS22 is eagerly awaited (Kelly and Evans, 2004).

5.8.3 Access to Information

PSD features such as Trombe walls and roof ponds are likely to be unknown by the vast majority of end users in the UK, particularly as they are not common features of buildings. Due to the lack of necessary infrastructure in place to support the wider use of PSD, there are few systems in place to increase people's knowledge of PSD features. End user awareness of PSD is an important issue that needs to be addressed. For those who are aware of PSD and wish to install features within their own home, it is currently difficult to find relevant information and guidance on PSD and how to use these features to their full advantage. When decisions are being made in relation to having a building extension or installing a new heating system, for example, PSD technologies are not sold alongside their conventional counterparts. Shops which sell fireplaces, air-conditioning units and lighting do not sell or stock PSD technologies. In addition, there are few specialists exist whom end users could contact in relation to PSD. Existing specialists, such as architects, architect technicians and builders, may not have the necessary knowledge or experience associated with such systems. This is a problem for PSD as end users may consult specialists for help and advice. For end users who do not have the necessary knowledge on PSD or general building practices, they will trust and rely on the expertise of architects and builders in this area. Therefore, it is essential that professionals have the necessary knowledge and training in PSD in order to professionally advise clients.

5.9 Key Challenges for PSD

This analysis has highlighted the many diverse issues facing the wider deployment of PSD in buildings in Sheffield. As summarised by Table 5.1, PSD uses a reliable energy source which is environmentally acceptable but problematic in meeting end user expectations of accessibility, ease of use, flexibility, convenience, consistency, affordability and quality. From this examination, it is evident that a series of obstacles face the use of PSD in new and existing buildings in Sheffield. In essence, there is a lack of infrastructure supporting the implementation of PSD technologies. At present, there is very little in place to introduce and promote PSD technologies, guarantee products and install and guarantee the correct installation of PSD in new and existing buildings. In addition, there are few systems in place to advise people on the operation of the technologies and maintain PSD systems. As a result, the wider deployment of PSD in Sheffield faces numerous obstacles, as summarised in Table 5.2. In Table 5.2, the obstacles are subdivided into those that affect the introduction and promotion of PSD, the installation of PSD and the operation and maintenance of PSD technologies. It is important to note that some of the obstacles raised in Table 5.2 overlap and will affect more than one stage of deployment. In order to actively pursue PSD as one way of reducing carbon emissions in urban areas, it is essential that ways of overcoming these obstacles are identified. These are considered for PSD and other renewable energy technologies relevant to Sheffield in Chapter 13.

Table 5.1 Current Evaluation of PSD against End User Expectations and Existing Energy Systems

End User Expectations	Existing Energy Systems	PSD
Accessibility	●●●	●
Ease of Use	●●●	●
Flexibility	●●●	●●
Convenience	●●●	●
Reliability:		
Now	●●	●
In the future	●	●●●
Consistency	●●●	●
Acceptability, in terms of:		
Affordability	●●	●
Quality	●●	●
Cultural expectations, in particular:		
Environmental concerns	●	●●
Sustainability	●	●●

Key to symbols:

● Does not meet expectations

●● Expectations are partially met

●●● Meets expectations

Table 5.2 Obstacles Facing the Deployment of PSD in Sheffield

End User Expectations and Additional Issues	Obstacles	Introduction & Promotion of PSD	Installation of PSD	Operation & Maintenance
Accessibility	The use of PSD depends on end user needs and characteristics of the building	■		
	The decision on whether or not PSD will be introduced through new build or by retroffing/refurbishing existing buildings	■		
Ease of Use	Lack of infrastructure in place to promote and sell PSD	■		
	Lack of trained specialists to install and/or maintain PSD systems		■	■
	End user unfamiliarity with the operation of PSD can lead to mis-use and increases in energy consumption			■
Flexibility	Problems may be encountered when retrofitting/refurbishing existing buildings with PSD.	■	■	■
Convenience	Inconvenient building work associated with adding PSD features to existing buildings.		■	
Reliability	PSD technologies and materials must be reliable and perform well.			
	Consumer understanding of how PSD systems operate			■
Consistency	Inconsistent and unconventional way of heating, cooling, lighting and ventilating buildings.	■		■
Acceptability	Unavailability of grants to help offset costs	■	■	
	Cheapest option is to install PSD into new build	■		
	Need quality reassurances to help motivate consumers to invest in PSD	■		
	Site-specific nature of PSD leads to site-specific environment impacts which must be addressed locally	■	■	
Perception of Risk	Building industry - perception of risk associated with unconventional buildings & resistance to change	■		
	Owners of buildings - perception of cost and marketability risks either when seeking to incorporate PSD features or when selling the building	■		
Planning Issues	Lack of precedent as few examples of adding PSD to existing buildings	■	■	
Access to Information	Lack of infrastructure in place to increase consumer knowledge of PSD including shops and specialists	■		

Key to symbol: ■ Obstacle affects this stage of deployment.

6. SOLAR ENERGY TECHNOLOGIES: ACTIVE SOLAR SYSTEMS

6.1 Active Solar Systems

Active solar systems have specialised collectors, which gather and convert solar radiation into thermal energy (heat). This energy source can be used for space heating, domestic hot water (DHW) heating and cooling purposes (IEA, 1997). The most common application is for DHW heating in the UK. In Sheffield, active solar DHW systems could provide approximately 2,300 TJ of heat to domestic buildings per year and save around 33,770 tC (Appendix D). At present, very few domestic buildings utilise available solar energy for heating purposes. In order to understand why this situation exists, it is necessary to examine the issues facing the practicality of using active solar systems in domestic buildings in Sheffield.

The chapter is subdivided into two parts. The first part (Sections 6.2 to 6.6) reviews active solar systems in the broad context of the UK. The basic aspects of active solar systems are introduced in Section 6.2. Then the resource considerations (Section 6.3) and applications (Section 6.4) are discussed. The technical and economic status of active solar systems is explored in Section 6.5 and 6.6, respectively. The second part of the chapter examines the ability of active solar systems to meet end user expectations of energy services and highlights the differences between active solar systems and conventional energy technologies in delivering hot water to consumers. Section 6.7 evaluates active solar systems against the relevant stakeholder demand criteria, which acts as a basis for this analysis. From this examination, obstacles facing the deployment of active solar systems in Sheffield are identified. In Section 6.8, additional issues facing active solar systems are examined. The key challenges facing active solar systems in Sheffield are summarised in Section 6.9.

6.2 Basic Aspects

Active solar systems comprise of a solar collector and a heat transfer medium (liquid or air) that conveys the heat from the collector to the point of use or storage (IEA, 1997). Active solar systems can be designed to provide between 40-80% of the heating needs of a building (DoE, 2004). For cooling purposes, the energy from the solar collectors drives an absorption chiller generator, which produces cool air or water (Anon, 1998). For low temperature applications, such as domestic water heating, collectors supply heat at temperatures from 20°C to 100°C (Ashley et al, 1996). For high temperature applications, such as those required to generate electricity, solar technologies are used to heat a fluid up to temperatures ranging from 400°C to 3,000°C for use in a turbo generator or engine (Ashley et al, 1996). For applications that require higher power outputs, collectors can be connected together to form arrays. However, for domestic applications, collectors typically cover an area of 2-4 metres squared (m^2). For a complete active solar heating system to operate, a number of other components are required. These components can consist of sensors for tracking, switches and/or motors to operate the system and provide back up heating, pipe work, a storage tank, filters for air systems, pumps and fans (DoE, 2004).

To ensure that the supply of thermal energy is reliable, the active solar system must be capable of supplying peak loads. If peak loads occur in the evening and supply of hot water or warm air exceeds demand during the day, storage is required. For small-scale DHW applications, such as single-family households, the water is stored in a cylinder, often separate from the collector (Solar Design Company, 2000). The storage cylinder matches the uncontrollable heat source to the varying demand for DHW (Solar Design Company, 2000). DHW storage units or diurnal storage units, store water on a daily basis. When the system cannot provide sufficient heat to produce hot water at the desired temperature at various times throughout the year, having a conventional heat source as a 'back-up' system can make up for any shortfall in supply (ETSU, 1994). Larger-scale applications, such as communal group and district heating networks, can supply heat to collections of buildings. For such systems to operate effectively, long-term seasonal storage is required. Seasonal storage is designed to meet variations in demand and supply during the course of the year. The type of storage unit used depends upon the type of each individual application and can include steel water tanks, gravel/water storage pits, natural aquifers, geothermal storage and chemical storage (Lottner et al, 2000). Long-term storage units require more space than DHW storage units. For space heating/cooling systems, large areas are required to store the energy and system equipment. Larger storage tanks are required to achieve the same thermal capacity for space heating as hot water systems. Large pipes, which are more difficult to insulate, and high power ventilators, that are required to circulate the air, take up space (Anon, 1998).

6.3 Resource Considerations

The power outputs of active solar systems are subject to variations in solar radiation. Solar radiation varies by geographic location, time of day, the seasons and weather conditions such as cloud cover and haze (IEA, 1991). The UK experiences solar radiation which is diffuse with long periods of low radiation levels. Therefore, the UK is suited to low temperature heating applications that do not require direct sunlight. For solar collectors to reach their full potential, the optimum orientation of the collectors is south facing, at an angle equal to the latitude of the building (Ashley et al, 1996). Collectors can also be positioned between a southeast to southwest orientation as the sun moves throughout the day and year (CAT, 1995). Overshadowing caused by obstructions such as trees or other buildings must be kept to a minimum, as even partial shadowing will reduce the performance of the collector (DoE, 2004). There are different active solar systems available which have been designed to avoid potential frost damage during colder months. These are explored further in Section 6.5.

6.4 Applications

The traditional applications of active solar power in buildings are the production of DHW and space heating. In the UK, active solar systems are mainly used for DHW production. Other applications include swimming pool heating, electricity generation, cooling systems and solar-aided district heating. Electricity generation is a high temperature solar application requiring long periods of direct sunlight and a large area of land for ground-mounted solar collectors. As such, this application is not well suited to the UK where long periods of low solar radiation are common and land-use pressures exist. Solar cooling systems are being developed in Southern European countries. Here, solar collectors supply air conditioning or heating to residential and office buildings as required during the summer and winter months, respectively (Papakonstantinou et al, 2000). Solar systems can supply heat or cool air to any type of building including domestic properties, industrial premises, hostels and hotels.

There are a number of architectural ways of integrating active solar collectors, as with other solar technologies, into urban areas. Active solar collectors are commercially available in a choice of frame colours (Solar Design Company, 2000). The collectors can be mounted on independent structures or on structures parallel to the surface of the building (Anon, 1998). Independent structures allow the collector to be positioned to receive the optimum orientation and inclination, whilst the latter means of parallel implementation has less of a visual impact. Collectors can also be integrated into the building, providing both an architectural and energy functions (Anon, 1998). They can be integrated as overcladding or can become part of the roof or façade of the building. Integration into the building allows collectors to be possible replacements for traditional roofing materials and wall cladding. The collectors can either maximise visual impact, if specified, or blend into structure of a building (Solar Design Company, 2000). Developments in the construction of large-scale storage allow the units to be integrated into urban areas. For example, the top surface of gravel/water storage constructions can be used for other urban functions such as streets or play areas (EDCL, 2000).

6.5 Technical Status

Active solar technology is at various stages of technological maturity and commercial availability. The most common collectors available on the market today are flat plate collectors and evacuated tube collectors. Flat plate collectors can either be glazed or unglazed. Glazed flat plate collectors are commonly used for water heating. Good quality glazed flat plate collectors have a collection efficiency of around 30% (Ashley et al, 1996). Unglazed flat plate collectors are not insulated and are less efficient than glazed collectors. Unglazed collectors are used for low temperature applications or where collector use is limited to days which have direct solar radiation. The latter would be suitable for heating swimming pools (Ashley et al, 1996). Good quality evacuated tube collectors have higher collection efficiencies of around 60% (Ashley et al, 1996). All commercially available collectors have a life expectancy of 25 to 30 years (EDCL, 2000).

The performance of active solar collectors is important all year round, especially in colder months. Resistance to frost damage is a major consideration facing the choice of solar collectors, particularly in the UK. Frost damage can be minimised by placing non-toxic antifreeze in the circulating water of solar collectors (NEF Renewables, 2000). Additionally, systems are available which have freeze tolerant pipe work or have a drain back system which empties the water from the collectors into the hot water tank during cold periods. Evacuated tubes are also suitable for colder climate as the heat exchanger is situated inside the building. Whilst evacuated tubes are energy efficient, rare problems, such as roof leakages, may occur as a result of fitting the tubes on the outside of the building to the heat exchanger inside the building.

Active solar systems vary in maturity by application. DHW systems and swimming pool heating systems are well established with the technology being available on the market for over 20 years (EUROPA, 2000). Space heating systems have experienced a low take-up, mainly due to the high costs of the systems and the large areas of collector that are required to supply sufficient heat in winter months (ETSU, 1999). Solar-aided district heating systems have been successfully demonstrated in Denmark and Sweden where district heating systems are commonplace. Less proven systems, such as solar cooling and industrial process heating, continue to be researched and demonstrated (EUROPA, 2000). Research and development is directed towards optimising the technical and economic aspects of systems, reducing costs, especially for space heating systems, and developing new technologies for cooling systems (EUROPA, 2000). In addition, improvements in construction are being investigated together with ways of reducing operating and maintenance costs, and extending the durability, reliability and efficiency of collector technology (EUROPA, 2000). Long-term storage units for district heating networks are being used in other European countries. Research and development continues to be directed towards achieving economical and reliable storage using different technologies (Heller, 2000).

6.6 Economic Status

Active solar systems have high initial capital investment costs although the economics of the system depends on the specific application. A wide variety of factors can influence the economics of the system (DG XVII, 1996). Costs will vary depending on whether the system is installed on an existing building or integrated into a new building, by professional contractors or by an individual with a do-it-yourself (DIY) kit. Also, the type of property, the pitch of the roof, how the collectors are mounted, the layout of existing plumbing and the scale of the application are important factors. To give an indication of the price range of individual active solar systems, Tables 6.1 and 6.2 show the cost and performance data for a typical DHW system and a typical solar heating system for heating an outdoor swimming pool (ETSU, 1999). The quality and durability of the collectors, system design and the method of installation influence the performance of a solar system. Once the system is installed, the annual running costs are low with minimal routine maintenance required.

Table 6.1 Cost Data for a Typical Solar Domestic Hot Water System (ETSU, 1999)

Typical system collector area	3-4 m^2
Typical system price - retrofit including VAT	£2,000-£6,000
Typical system price - DIY including VAT and new-build	£1,000-£2,500
Annual pump running costs	£6/year
Installation time	0.1 years
Assumed lifetime	25 years
Annual output	1,000-1,500 kWh(thermal)

Table 6.2 Cost and Performance Data for a Typical Solar Heating System for an Outdoor Swimming Pool (ETSU, 1999)

Typical system collector area (assuming existing pool pump is running)	20 m^2
Typical system price (including VAT) (includes DIY and professionally installed systems)	£950-£2,700
Annual running costs	Negligible
Installation time	0.1 years
Expected lifetime	15 years
Annual output (based on use from May to September)	~6,000 kWh(t)

The cost data provided in Tables 6.1 and 6.2 illustrate the large price range of individual systems installed in new buildings, retrofitting existing buildings and DIY applications. One way to improve the economics of the systems would be through the introduction of communal or district heating systems, especially in new developments. Heat can be supplied to a group of buildings connected to a heating network. By sharing heat, the storage facilities can be shared and the heat supplied can meet variations in demand (OECD, 1995). In European countries, large-scale solar heating systems have proven to be more cost effective than single DHW applications, where costs can be reduced by approximately a third (Fisch et al, 1998). The integration of solar-aided district heating systems into the design and development of new housing estates have also proven to be more cost-effective than retrofit. Costs are influenced by storage costs in relation to the materials used, the nature of the construction and the performance of the system. The economics improve with larger solar systems and storage units (Lottner et al, 2000).

There are differing views on the future costs of active solar systems. As the technology is mature and commercially available with some of the components used coming from the plumbing industry, the potential for further cost reductions is low (ETSU, 1999 and Jackson and Löfstedt, 1998). It has been suggested that further cost reductions could be achieved by reducing overhead and marketing costs (ETSU, 1999). For specialised components in the active solar systems, costs are only likely to reduce once economies of scale have been established, through increased demand and higher production rates (ETSU, 1999). As the technology is largely mature, it has been predicted that the demand for active solar systems will only increase during periods of 'heightened environmental concern' (ETSU, 1999). Although the economics of large-scale applications are more attractive, district heating networks are uncommon in the

UK due to poor experiences with district heating systems and the low price of fossil fuels.

6.7 Meeting Stakeholder Expectations

6.7.1 Active Solar Systems and Domestic End Users

Out of the total energy used in domestic buildings, approximately 80% is used for space and water heating purposes (DEFRA, 2002). At present, domestic buildings in Sheffield consume large quantities of natural gas and electricity, the majority of which is likely to be used for heating requirements (Chapter 3). Although some domestic buildings have solar collectors for hot water heating, they are in the minority. In order to introduce active solar systems as a way of heating homes, solar collectors could be added to new build or existing buildings. As with PSD, new build offers an opportunity for installing active solar systems in buildings. However, the practical realisation of this has a long time scale. Therefore, in order to move towards active solar systems as a way of reducing carbon emissions, retrofitting existing buildings either solely for energy purposes or in combination with routine building work presents potentially quicker opportunities for change.

In existing buildings, the decision to replace conventional heating systems with an active solar system resides with the end user. In the domestic sector, there are four main types of decision-maker, namely owner-occupiers, private property owners, local authorities and registered social property owners (ODPM, 2003b). Owner-occupier's either own the house they are living in or are in the process of purchasing it with a mortgage or loan. Other individuals, local authorities and organisations, such as Housing Associations, own buildings or are in the process of buying them for the purposes of privately renting the property (ODPM, 2003b). The relationship of the occupier to the household is important when decisions are made on how the building will be heated and who will finance these changes. Additionally, how the occupier interacts with the energy systems affects energy consumption. As with PSD, it is important that any move towards renewable energy substitutes existing demand rather than increases energy consumption. In new build, the decision to install active solar systems rests with architects, architect technicians and developers.

In order for active solar systems to replace existing ways of heating domestic buildings, the systems must meet the expectations of end users. End users expect energy services to be accessible, easy to use, flexible, convenient, reliable, consistent and acceptable, as identified in Chapter 2. This examination is necessary in order to identify any obstacles which will affect the wider deployment of active solar systems in Sheffield. The ability of active solar systems in meeting these expectations is examined below.

6.7.2 Accessibility

There are two main questions surrounding the accessibility of active solar systems by the domestic user, namely, are all domestic roofs suitable for solar DHW collectors and can energy supply be matched to energy demand? Existing buildings can pose a problem for active solar collectors as the orientation of the building, the pitch of the roof and overshadowing, to some extent, is already pre-determined. Based on the MIRE assessment of solar DHW potential within the domestic sector in Sheffield, up to 80% of domestic roofs were assumed to be suitable for active solar collectors (Grant et al, 1994c). This implies that, although there may be some problems with existing buildings such as pre-determined building orientation, roof pitch and overshadowing, there is an overwhelming potential for active solar hot water systems in Sheffield within the existing building stock. With new build, these issues can be easily resolved as there is more control over the orientation of the building, pitch of the roof and surrounding objects such as trees and buildings. End user access to hot water and space heating at any time of the day or night is another key issue facing active solar systems. As solar energy supply is only available during the day, storage is required to match supply with demand, as outlined in Section 6.2. Additionally, a conventional back-up supply could be used in case a short-fall in supply occurs, for example, during the winter months. If solar collectors were developed as part of a district or group heating system, single storage in one location could be developed.

6.7.3 Ease of Use

In relation to ease of use, active solar systems are similar to PSD features as there is limited infrastructure in place to sell, install and maintain active solar systems. Additionally, there are no systems in place to guarantee the performance of active solar collectors and the correct installation of the collectors. Active solar systems are not commonly installed throughout the UK. Unfamiliarity with this technology and the perception of it being new and difficult to use, may affect the purchase and operation of such systems as discussed earlier in relation to PSD in Section 5.7.3.

6.7.4 Flexibility

End users expect energy to provide them with a number of different energy services. Although active solar systems can be used to meet a wide variety of heating and cooling needs, as outlined in Section 6.4, the most common application of active solar systems is likely to be for hot water and space heating applications in Sheffield. As noted earlier, heating demands in domestic buildings accounts for the majority of energy consumed by this sector. In order to ensure flexibility of supply, storage is required to ensure that energy supply meets demand.

6.7.5 Convenience

The installation of active solar systems on existing roofs as part of retrofit or refurbishment work, and end user familiarity with the operation of such systems affects their convenience. Most building work is regarded as inconvenient. However, the level of inconvenience can be reduced by incorporating a number of changes into a single refurbishment of a building. This compares with retrofitting existing buildings solely for the purpose of installing active solar systems. For new build, the inclusion of active solar systems into the overall construction of a building is not inconvenient. As active solar systems are not commonly used in the UK, end users are unfamiliar with this technology. Until a building's occupants become familiar with the operation of active solar systems, the system may initially be regarded as inconvenient.

6.7.6 Reliability

In order for active solar systems to be attractive to end users, the energy supply and technology needs to be reliable. As previously established, solar energy is a reliable and carbon neutral energy source which makes it suitable for energy exploitation (Section 5.7.6). When adding active solar systems to buildings, it is important that the solar collector, its installation and the overall performance of the system is reliable and performs in accord with end user expectations. This raises the issue for the need for guarantees to be placed on the materials used, the product and the installation of active solar systems. In addition to guarantees, end user interaction with the system may also affect the performance. Any mis-management could result in active solar technology being labelled as inefficient and unreliable by users.

6.7.7 Consistency

End users expect energy services to be consistent, both now and in the future. Therefore, changing from conventional ways of heating domestic buildings to active solar systems must continue to deliver the same benefits as conventional heating systems. The supply of heat is an important energy service. Active solar systems are both similar and different to conventional ways of heating buildings. The main similarity is that they both provide heating on a building-by-building basis, although there is the potential for large scale production to occur. At present, the heating of domestic buildings in the UK is mainly decentralised with few large-scale district heating systems producing and supplying heat to end uses via a distribution network. Although a district heating system exists in Sheffield, the majority of its end users are located in buildings used for business and industrial activities within the city centre. Active solar systems are inconsistent with conventional heating systems as they use solar energy, which is not widely utilised for energy generation purposes within the UK. Additionally, the technology used to collect and convert the energy supply is located externally on the building i.e. on the roof. The installation of active solar collectors on the roofs of domestic buildings raises questions over who owns the roof and who has responsibility for the system. Should it be the owner of the building? The occupier of the building? The company who installed the system? The manufacturer? Or should the responsibility lie with a new type of heating company who installs and oversees active solar system projects? These questions need to be explored further if active solar systems are to become common features of domestic buildings in Sheffield.

6.7.8 Acceptability

The acceptability of active solar systems can be divided into affordability, quality and environmental acceptability. The affordability of active solar systems varies greatly depending on the individual application and local conditions. Although the energy is "free," the cost of installing a system can be expensive. In order to combat economic issues and to encourage the uptake of active solar systems further, a three-year programme of capital grants is being developed for community and household schemes, which includes solar water heating applications in the UK (DTI, 2002a). It is intended that one of these schemes, entitled "The Community and Household Capital

Grants Scheme" will be aimed at domestic households or buildings/land owned by non-profit making organisations (DTI, 2002a). However, the extent to which these schemes will exist in the wider deployment of active solar systems in the domestic sector has yet to be seen.

The integration of active solar systems into the design of new buildings can be significantly cheaper than refurbishing existing buildings. By integrating systems into new developments, it is possible that active solar heating could supply a group of buildings with heating. Also collectors and storage units can be integrated into the area to minimise any visual impacts and maximise available space, although with careful planning, this could be achieved in existing areas. Through the development of district heating networks, community ownership schemes may emerge where heating needs are managed by local people rather than traditional energy suppliers. Despite the advantages of district heating and community ownership schemes in promoting the uptake of active solar systems, such schemes are not commonplace in the UK.

The quality of energy service is a key issue for end uses who change energy suppliers. Whatever the energy supply or heating system, end users expect a quality product and supply of heat. As such, there is a need to ensure that quality active solar systems are produced and installed correctly. This also links to the issue of guaranteeing products and their installation, operation and maintenance, particularly as a way of encouraging end uses to switch to active solar systems as an alternative way of heating their home.

The environmental benefits of using solar energy have also been examined previously in Section 5.7.8. In comparison with PSD, the installation of active solar systems is site specific. Placing solar collectors on the roofs of domestic buildings raises questions concerning the environmental impact of the collectors, especially visual impacts. Unlike conventional energy generation and supply, local energy generation from solar collectors means that local communities will be required to manage and mitigate against any negative environmental impacts created from installing energy technologies within cities rather than external to the city.

6.8 Additional Issues

6.8.1 Planning Issues

Solar collectors can either be incorporated into the design of new buildings or fitted to existing buildings. In the case of new buildings, it is unlikely that planning issues will arise, as the planning application for the new development will include the solar systems. Adding solar collectors to existing buildings may raise a number of planning issues. Incorporating the collectors into the façade cladding of a building, onto roof tiles or onto free-standing frames is likely to alter the character or roof slope of a building. Under the Town and Country Planning Act 1990, such developments normally require planning permission (ODPM, 1995). Local environmental constraints such as the historical status and location of the building will influence planning permission decisions. Any proposals to install active solar collectors on Listed Buildings, within the grounds of a Listed Building or in designated areas like National Parks, will require planning permission (ODPM, 1995).

A long standing issue facing active solar systems and other renewable energy developments has been the lack of precedent in this area, limited awareness of renewable energy technologies and their applications and poor access to information. The lack of precedent may cause problems in the deployment of active solar collectors within Sheffield, especially as uncertainty raises doubts amongst key decision-makers. Additionally, if end users are unaware of the availability of active solar systems when seeking to change or improve their domestic heating system, the uptake of active solar will remain low. It is hoped that the new PPS22 will help to alleviate some of these issues and make Local Authorities more pro-active in encouraging and supporting local renewable energy developments.

6.8.2 Health Issues

Any hot water system or large air conditioning plant runs the risk of legionnaire's disease. The bacterium Legionella, which causes the disease, is naturally found in water. At low concentrations, it is not a health hazard. However at high concentrations, Legionella can pose a serious health risk especially to the elderly, people with underlying diseases and those who smoke. In conditions where water temperatures are between 25°C and 45°C, Legionella can quickly multiply (Sadler et al, 1996). There are a number of precautions which can be taken to minimise any risk.

The most important precautions are to ensure that all hot water is heated to 60°C, cold water temperatures do not rise above 20°C and to ensure that the system is properly installed and maintained (Sadler et al, 1996).

6.8.3 Legal Issues

Solar access may become a legal issue in cases where the construction of new buildings overshadows an existing active solar system. Solar access is a term used for protecting a building's access to sunlight (DoE, 2004). Any shading of solar collectors reduces the performance of the system. Solar access can be restricted by a range of objects including trees, plants and chimneys. For active solar collectors, it is unlikely that existing obstacles, such as trees, should be removed when placing solar collectors on a building. With new build, any potential shadowing from surrounding objects can be minimised by changing the orientation of the building.

6.8.4 Insurance Issues

General household insurance policies cover damage to most DHW systems, except frost damage. However, in certain instances, the systems may not be fully covered against damage. Failure to inform the insurance company of the installation of the system, fitting the system without notifying the correct authority and failure to take reasonable care of the system, may result in the system not being fully covered (Sadler et al, 1996). Active solar systems can be susceptible to leaks, collector breakage, frost and storm damage (Sadler et al, 1996). However, care and maintenance of the systems can minimise risk from most causes of damage.

6.9 Key Challenges for Active Solar Systems

This analysis of active solar systems has shown that there are many issues facing the wider deployment of such systems in domestic buildings. As summarised in Table 6.3, active solar systems meets end user expectations of accessibility, flexibility, reliability and environmental acceptability. From this examination, it is clear that active solar systems share problems faced by the wider deployment of PSD features in Sheffield. As summarised by Table 6.4, there are obstacles facing the introduction, promotion, installation, operation and maintenance of active solar systems. These obstacles, in turn, affect the ease of use, convenience, consistency, affordability and quality of active solar systems and the energy service they provide. Similarly to PSD, the lack of

Table 6.3 Current Evaluation of Active Solar Systems against End User Expectations and Existing Energy Systems

End User Expectations	Existing Energy Systems	Active Solar Systems
Accessibility	●●●	●
Ease of Use	●●●	●
Flexibility	●●●	●●
Convenience	●●●	●
Reliability:		
Now	●●	●●
In the future	●	●●●
Consistency	●●●	●
Acceptability, in terms of:		
Affordability	●●	●
Quality	●●	●●
Cultural expectations, in particular:		
Environmental concerns	●	●●
Sustainability	●	●●

Key to symbols:
- ● Does not meet expectations
- ●● Expectations are partially met
- ●●● Meets expectations

infrastructure surrounding the introduction and utilisation of a new energy technology is a major obstacle to the adoption of active solar systems. In order for solar DHW collectors to replace conventional heating technologies, ways of overcoming the obstacles need addressing. These are considered for active solar systems and other renewable energy technologies relevant to Sheffield in Chapter 13.

Table 6.4 Obstacles Facing the Deployment of Active Solar Systems in Sheffield

End User Expectations and Additional Issues	Obstacles	Introduction & Promotion of Active Solar	Installation of Active Solar	Operation & Maintenance
Accessibility	Adding solar collectors to existing buildings due to pre-determined factors.	■	■	
	Matching supply of hot water and heat to demand	■		■
Ease of Use	Lack of infrastructure in place to guarantee the performance of collectors and their installation	■	■	
	End user unfamiliarity with active solar technology	■		■
Flexibility	Without storage, active solar systems cannot provide a flexible energy service	■	■	■
Convenience	Inconvenient building work associated with adding solar collectors to buildings		■	
	End user unfamiliarity with active solar systems may lead them to be labelled as inconvenient			■
Reliability	Active solar systems must be reliable and perform to end user expectations	■		■
	End user understanding of how active solar systems operate			■
Consistency	Inconsistent way of heating buildings			
	Roof ownership and responsibility issues	■		■
Acceptability	End user awareness of grant availability	■		
	Move from current heat provision to community or district-based schemes	■		■
	Need quality reassurances of product, installation and operation	■		
	The local community will be required to manage & mitigate any adverse environmental impacts associated with local energy generation	■	■	
Planning Issues	Adding solar hot water panels to existing buildings is likely to require planning permission and there may be issues concerning lack of precedent in this area	■		
Health Issues	Risk of Legionella's disease	■	■	■
Legal Issues	Solar access	■	■	■
Insurance Issues	Frost damage implications	■		■

Key to symbol: ■ Obstacle affects this stage of deployment.

7. SOLAR ENERGY TECHNOLOGIES: PHOTOVOLTAICS

7.1 Photovoltaics

Photovoltaics (PV) or solar cells are a means of converting solar radiation directly into electrical energy. In Sheffield, it has been estimated that energy efficient buildings consume around 9,000 TJ of electricity per year. This consumption results in the release of approximately 339,000 tC per year (Appendix C). By placing PV panels on suitable roofs and façades of business and industrial buildings, solar electricity could supply 5,122 TJ of electricity to buildings in Sheffield and save around 192,000 tC per year (Appendix D). This energy could be utilised solely by business and industrial practices and/or supplied to domestic buildings to meet some of their electricity needs (Appendix D). Although PV has potential in Sheffield, very few buildings currently utilise available solar energy for generating electricity. In order to understand why this situation exists, it is necessary to examine the technical and non-technical issues facing the wider deployment of PV systems on buildings in Sheffield.

In order to address these issues, this chapter is subdivided into two parts. The first part (Sections 7.2 to 7.6) reviews PV in the broad context of the UK. The basic aspects of PV are introduced in Section 7.2. Then the resource considerations (Section 7.3) and applications (Section 7.4) are discussed. The technical and economic status of PV is explored in Sections 7.5 and 7.6, respectively. The second part of the chapter examines end user expectations of energy services and highlights the differences between PV and conventional energy technologies in supplying consumers with electricity. Section 7.7 evaluates PV against the relevant stakeholder demand criteria, which act as a basis for this analysis. From this examination, the problems facing the utilisation of PV in Sheffield are identified. In Section 7.8, additional issues facing PV are examined. The key challenges facing PV are summarised in Section 7.9. The differences between PV and the existing energy system in meeting stakeholder expectations are summarised. The obstacles facing the deployment of PV in Sheffield are also considered.

7.2 Basic Aspects

PV cells can be designed to supply power from a few watts to thousands of watts (Hill et al, 1995). The cells are electronic devices made from thin slices or wafers of semiconductive materials, mainly crystalline or amorphous silicon (Hill et al, 1995). Each cell typically has an area of 100 centimetres squared (cm^2) and, in bright sunlight, the cells have a power output of 1.5 watts (W) (Ashley et al, 1996). To increase this power output, individual cells are grouped together in modules. Whilst the shape and size of modules vary, they typically contain 30-36 cells and produce 40-60 W in peak sunlight (Ashley et al, 1996). For applications requiring a higher power output, modules are connected together to form arrays. Modules must be strong enough to withstand changing weather conditions and protect the cells and their electrical components from moisture and pollution over the cell lifetime (Hill et al, 1995). For a complete PV system to operate, a number of other components are required. Often referred to as the "balance of system", these components consist of a distribution box, an inverter, battery storage, which is optional, current and voltage regulators, power controls and other structural parts (IEA, 1991).

The size of the PV system depends upon the expected energy consumption and peak power demands of the application (Sick and Erge, 1996). To ensure that the electrical supply is reliable, the system must supply peak loads. If peak loads occur at night and supply of electrical energy exceeds demand during the day, storage is required. Electrical power from PV systems can be stored in batteries or supplied to the national grid. Storing large amounts of power in batteries can be very expensive (EDCL, 2000). The PV system can be connected to the national grid using meters to record imported and exported power (Ashley et al, 1996). Grid connection also provides a 'back-up' system should demand exceed supply. There are two metering options currently available in the UK, namely one-way meters for incoming supply and two-way meters for imported and exported electricity. In countries outside the UK, where the buying and selling price of electricity is the same, a single meter is used to measure imported and exported electricity (Max Fordham and Partners, 1999).

7.3 Resource Considerations

The power outputs of PV cells are subject to variations in solar radiation and the orientation and inclination of the cell. The orientation and inclination of the solar cell affects the amount of sunlight received by the cell. For solar cells to reach their full potential, it is necessary for the cell to be orientated at an inclination that receives the greatest amount of sunlight. For south-facing PV panels, the optimum inclination should be equal to the local latitude (Sick and Erge, 1996). For east to west facing PV panels, the panels gain 60% of the solar radiation received by south-facing panels, due to the low angle of the sun at the beginning and end of the day (Sick and Erge, 1996). It is important to keep PV modules well ventilated as the performance of the modules decreases with rising temperatures. Shadows should also be kept to a minimum as they reduce the electrical output of PV panels (Max Fordham and Partners, 1999).

7.4 Applications

PV systems can be designed to supply energy for a wide range of applications. The main uses which have emerged for PV cells are in space applications to power satellites, the operation of a growing number of consumer products including calculators, watches and clocks and for stand-alone appliances. PV systems are used for rural applications such as monitoring and control devices and lights and to meet the power loads of farms and houses not connected to the national grid (Hill et al, 1995). PV systems can be used in urban areas to meet the electrical loads of domestic and non-domestic buildings. In towns and cities, PV systems have three main applications:

- Stand-alone units – These units are easy to position to the optimum orientation and inclination. As the units are not connected to the national grid, they require battery storage.

- Façade cladding - PV systems can be attached to the façade of existing buildings or incorporated into the design of new build. One example of the use of PV façade cladding in the UK is the Northumberland Building at the University of Northumbria.

- Roof-mounted arrays - Fastened to secure structures, the arrays can be either fixed in the best position on the roof to receive the optimum solar radiation or driven by motors to track the changing position of the sun (Ashley et al, 1996).

There are a wide variety of architectural ways of integrating PV systems into urban areas. PV tiles and panels are commercially available in a variety of colours including black, blue, red, green and yellow, and can be transparent or opaque (Ashley et al, 1996). This makes them possible replacements for traditional roofing materials and wall cladding.

7.5 Technical Status

PV cell technology is at various stages of technological maturity and commercial availability. There is a constant drive to improve the conversion efficiencies and lifespan of cells whilst reducing manufacturing costs. The most common cell technologies available on the market today are mono-crystalline and poly-crystalline silicon cells, accounting for half of Europe's production of PV cells in 1996 (Jackson and Löfstedt, 1998). Commercial modules comprising of crystalline cells have conversion efficiencies of around 14% and a lifespan of 25-30 years (Hill et al, 1995 and EUROPA, 2000). Thin film cell technology is also commercially available. The most common thin film cell technology is made from amorphous silicon, which accounted for 25% of European PV production in 1996 (Jackson and Löfstedt, 1998). Although thin film cells have low conversion efficiencies of around 6%, their manufacture uses less materials therefore reducing manufacturing costs. Thin film amorphous silicon cells degrade over time and loose their efficiency (Hill et al, 1995). These cells are commercially available for low power applications such as watches and calculators.

At present, the lifespan of PV systems ranges between 25-30 years with the life of cells ranging between 15-30 years (EUROPA, 2000). Research and development is directed towards increasing the lifespan of PV cells to beyond 30 years, improving cell efficiency and reducing manufacturing costs. A number of advancements in cell technology are currently being explored including reducing the wafer thickness of crystalline silicon cells and using cadmium telluride, copper indium diselenide, gallium arsenide and titanium dioxide in thin film technology (ICLEI, 2000b). Research is taking place in developing different types of concentrator cells which have high conversion efficiencies. Concentrator cells concentrate light from a large area onto a small solar cell (Jackson and Löfstedt, 1998). Multi-junction concentrator cells are built up from several layers, each collecting a different part of the solar spectrum (Jackson and Löfstedt, 1998). Work is also being undertaken to develop frameless modules to avoid the use of energy-intensive support structures and frames (Alsema and Nieuwlaar, 2000).

There is a common assumption that the future prospects of PV cell technology are good. With investments into achieving greater cell efficiencies, longer cell lifetimes and lower manufacturing costs, PV systems are likely to become more commercially viable for a wide variety of applications. However, there is still significant scope for cost reduction and performance improvement of PV cells (ETSU, 1999).

7.6 Economic Status

At present, initial capital investment costs for PV systems are high, although the costs vary depending upon the type of application and PV cell technology used. It is likely that relative costs will fall over time. To illustrate present and likely future costs, cost trends of PV are shown in Table 7.1. Once the system is operational, annual running costs are low with minimal routine maintenance (ETSU, 1999).

Table 7.1 Present and Likely Future Photovoltaic Cost Data (ETSU, 1999).

Costs	1997	2010	2025
PV module (£/m^2)	234-422	184-266	36-102
Inverter (£/kW):			
Domestic system	1060	520	250
Non-domestic	600	360	250
Wiring (£/m^2)	55	38	30
Operation and maintenance (£/kWh generated)	0.005	0.005	0.005

The economics of grid connection and the price that electricity utilities buy PV generated electricity act as barriers to PV developments in the UK. Grid connection prices vary and can form a significant part of the costs of the system. Periodic charges for grid connection and services of the electricity company may amount to 20% of the annual income of a commercial system and 60% of the income of a domestic system (Halcrow Gilbert Associates Ltd, 1993). Costs can be reduced if meters are installed when the PV system is fitted so that no additional fixed charges are made by the electricity company (Halcrow Gilbert Associates Ltd, 1993). At present, electricity utilities charge domestic consumers between 6-7.5p per kilowatt hour (kWh) purchased and pay between 2.5-4p per kWh for PV electricity exported to the grid (Anon, 2000b).

In addition to considering current electricity prices, there are differing views on the future cost of electricity from PV systems. It has been estimated that electricity produced from PV sources for non-domestic applications will not fall below 7p/kWh by 2010 and 15-20p/kWh for domestic applications assuming an 8% discount rate and 25 year lifetime for the latter (ETSU, 1999). Although there has been a past trend of falling industrial and domestic electricity prices, prices are now rising. Limited electricity generation capacity combined with a shortage in low cost natural gas is the reasons behind the price rise. The price of natural gas directly influences electricity prices as natural gas is a competitive fuel and is used to produce electricity. In 2000, coal was the main fuel used for electricity production (36%) followed closely by natural gas (34%) (DTI, 2003b). The rise in natural gas and electricity prices has been felt by the consumer. Domestic electricity bills have risen and industrial bills are expected to rise by 2010 (EEF, 2004). The recent price rise is favourable for electricity produced from PV and other renewable energy sources. Traditionally, there has been an absence of equal competition between electricity produced from conventional and renewable energy sources (Shaw, 1999). Rising electricity prices may, over the longer term, stimulate a more competitive and level playing field for electricity produced from renewable energy sources. Additionally, if this situation continues, greater investment in PV and other renewable energy sources may occur.

7.7 Meeting Stakeholder Expectations

7.7.1 Photovolatics and End Users

In order for PV to replace existing ways of providing electricity to buildings in Sheffield, it must continue to meet the expectations of end users. In the case of PV, end users are the owners/occupiers of business and industrial buildings. However, there may be some opportunity to export electricity to domestic users. Introducing PV as an alternative way of producing electricity in Sheffield would require the involvement of key decision-makers within the business and industrial sector. The owners, and possibly the occupiers, of business and industrial premises have an important role in localised electricity generation, as their buildings have been identified for solar PV generation (Grant et al, 1994c). Installing PV on existing buildings, either through retrofit or refurbishment, offers immediate opportunities and shorter timescales to reduce carbon emissions when compared to integrating PV into the design of new buildings. Although it is easier to install PV into new buildings, the replacement rate of buildings is low in the UK. Decisions need to be made on whether carbon emissions and sustainable urban energy systems are going to be achieved over the longer term or whether more immediate changes are going to be pursued. If new build was identified as the way forward for business and industrial PV in Sheffield, and action plans were pursued immediately, it may take up to 100 years before each building in Sheffield has PV panels (Section 5.7.2). If more immediate reductions in carbon emissions are sought, an alternative option would be to incorporate PV into the roofs and façades of existing buildings through retrofit and refurbishment work.

An essential requirement for promoting the uptake of PV by the business and industrial sector is to assess if it can meet end user expectations of accessibility, ease of use, flexibility, convenience, reliability, consistency and acceptability, as identified in Chapter 2. This examination is necessary in order to identify any obstacles which will affect the wider deployment of PV in Sheffield. The ability of PV in meeting the expectations of end users is examined below.

7.7.2 Accessibility

The extent to which PV is accessible by all end users in Sheffield depends on the characteristics of the building and the availability of information. The orientation of the building, pitch of the roof and overshadowing is an issue for PV. It is more difficult to change these factors with existing buildings as opposed to new build. In Sheffield, it has been assumed that 5% of the roof area and façades of business buildings and 5% of the roof area of industrial buildings are suitable for PV panels (Grant et al, 1994c). The MIRE assessment assumed that PV would not be installed on domestic buildings as these are more likely to be fitted with solar hot water systems (Grant et al, 1994c). Despite these assumptions, the opportunity also exists for business and industrial owners to export excess electricity onto the national grid, for consumption by domestic users. End user access to information and advice is another key issue. Whilst energy agencies are available to guide people and organisations and written report and guidance is available, awareness of, and access to, this information can be a problem for potential PV investors.

7.7.3 Ease of Use

There are three important issues surrounding the ease of use of PV. From the end user's perspective, are PV systems easy to choose as an alternative way of supplying business and industrial buildings with electricity and how easy are PV systems to operate? In relation to moving towards the wider use of PV in cities, the question over how easy will it be to persuade electricity users to install PV systems arises. If building owners make the decision to move towards PV generated electricity, there is limited infrastructure in place in the UK to sell, install and maintain PV systems in buildings. This may impede any decision of having a PV system and getting such a system up and running. However, efforts are presently being made by the Energy Savings Trust to accredit PV organisations as part of the DTI's Major PV Demonstration Programme (EST, 2004). Such an accreditation scheme may help to guarantee the performance of the technology and its installation. Although such schemes are a positive step in the right direction, it is necessary to ensure that potential end users of PV technology know who to contact and are aware of such schemes.

Another issue which may affect the use of PV is the perception that PV is difficult to use. Although solar energy has been used to power calculators for many years, PV panels are not commonplace on urban buildings. Despite the growing number of PV applications in the UK, end user unfamiliarity may be a problem, particularly as PV systems do not conform to conventional ways of supplying buildings with electricity. At present, electricity is produced in central large-scale power plants and supplied directly to buildings via the national grid and local networks. Placing PV panels onto the roofs and façades of individual buildings moves electricity generation away from a centralised system to a decentralised system, using small-scale plants located on individual buildings. This unfamiliarity with PV technology and local electricity generation is likely to influence potential investors in PV technology. Additionally, poor understanding of how PV systems work and subsequent mis-use of the systems by end users could lead to electricity wastage and the system being labelled as ineffective with poor performance levels.

Encouraging existing electricity end users to become electricity generators is unlikely to be easy. The current infrastructure in place to generate, distribute and sell electricity means that electricity is available at the flick of a switch. Additionally, industry receives special electricity tariffs which may act as a dis-incentive for industry to invest in its own electricity generation. As such, the transition towards localised PV electricity generation is likely to face many problems. It is unlikely to be easy to encourage businesses and industry in Sheffield to invest in PV systems when they already use electricity from the grid. If end users regard the current system as easy to use and prefer use the easiest option, this may inhibit the uptake of PV within Sheffield.

7.7.4 Flexibility

For any end user, it is important to match supply to demand. As electricity from PV is produced during the day, storage is required to meet electricity demands during the evening/night. Without storage, PV electricity cannot be regarded as a flexible energy supply. There are two main ways in which electricity can be stored, namely in batteries or feeding electricity back into the national grid. Storing electricity is likely to come at a cost for the potential PV generator. Using batteries to store large amounts of electricity can be very expensive (EDCL, 2000). Selling electricity back to the national grid using two-way metering is problematic as electricity suppliers do not often buy back electricity from small-scale generators for the same price at which they sell the electricity. It is important for potential PV users to take these additional cost issues into consideration. In the UK, electricity suppliers are largely unfamiliar with the prospect of buying electricity from small-scale generators. At present, their role is to sell and supply electricity to end users rather than enter into contracts with consumers to buy and sell electricity and manage supply and demand. If PV systems became more widely used within an urban context, the role and relationship of energy suppliers to local electricity generators would need to change.

7.7.5 Convenience

Moving towards a decentralised electricity generation system, also named embedded generation, has its advantages. Generating electricity on a local basis with adequate storage can provide extra security, particularly when blackouts occur. Transmission losses can also be reduced as the point of consumption is near the point of production. In a broader context, using PV locally can help to diversify energy production within the UK. However, despite the convenience of having local electricity generation, introducing PV into the urban environment could be initially regarded as inconvenient as the connection of a large number of PV systems to the national grid would require a great deal of management and organisation. The addition of PV panels to existing buildings and end user unfamiliarity affects the perception of the convenience of PV systems. Retrofitting or refurbishing existing buildings with PV raises issues over the convenience of installing PV and associated building work. Retrofitting existing buildings solely to install PV panels is disruptive. However, by incorporating PV work with other building activities, such as re-roofing or cladding of façades, this may help to reduce the inconvenience imposed on the building occupiers.

7.7.6 Reliability

End user confidence in energy supply and new technologies are an important aspect in consumer decision-making and spending. Although solar energy is a reliable, carbon neutral energy source, which can be predicted through the use of clear sky incident solar radiation data, end users also need guarantees that PV panels, their installation and operation perform according to their expectations. When installing PV panels onto a building either through retrofit or refurbishment, the appearance of the roof or façade is likely to be changed. Therefore it is important that the technology and materials perform in accordance with the expectations of end users. In some cases, PV panels or cells could replace existing roofing. In this situation, it is necessary that the panels not only generate electricity but also provide the occupants of the building with shelter and warmth.

In addition to technology and material guarantees, end users need to be confident that the panels are installed properly. Although the panel's performance could be guaranteed, if the architect or builder designs or installs the panel on the north side of the building at a 45° angle away from the sun, the panel will not perform. As with PSD and active solar hot water collectors, the product, its installation and performance are intrinsically linked. In addition, mis-management of PV systems by the end user could result in the performance of the panels being lowered. This may have the negative repercussion of PV being labelled as unreliable.

7.7.7 Consistency

As raised earlier, PV provides end users with a familiar energy service; electricity. However, the way in which this electricity is generated is more consistent with energy generation of 100 years ago. During the latter part of the nineteenth century and early part of the twentieth century, energy was produced and consumed locally rather than having large centralised plants with a national supply network (Chapter 2). Using PV to generate electricity raises issues concerning the move towards local embedded or decentralised electricity generation, as noted in Section 7.7.3. In particular, this type of electricity generation raises questions concerning the ownership of roofs and roof space and the role of electricity suppliers. As mentioned previously, PV panels can be placed directly onto roofs or integrated into the fabric of the roof (Section 7.4). If the PV system is owned by the owner and/or occupier of business and industrial buildings, the electricity is likely to be used for onsite consumption. Any excess electricity could be exported to nearby users or the national grid. In this situation, the building owner is likely to own the roof. However, opportunities may exist for electricity suppliers to have a more pivotal role in local PV developments. Should a situation develop whereby the energy supplier installs and maintains the PV system, over a given length of time, will the building owner or the electricity supplier be responsible for the roof? This, in turn, raises questions concerning the ownership and renting of roof space and cost and insurance implications. The issues raised here present opportunities for wider involvement by businesses, industry and traditional electricity suppliers in local PV electricity generation within Sheffield.

7.7.8 Acceptability

End uses expect energy services to be affordable, of a certain level of quality and environmentally acceptable. As with active solar hot water systems, the cost of installing a PV system varies depending on the site and local conditions. In order to encourage the uptake of PV systems, funding is available to assist capital costs of PV systems through the first phase of the DTI's Major PV Demonstration Programme (EST, 2004). Funding is available for individual applications on a small-scale which includes householders, schools, community groups and small businesses, where the funds are allocated on a first-come first-served basis as long as basic criteria are met. For private developers, local authorities and larger companies, funding is available on a competitive basis (DTI, 2002a). Although such opportunities exist, it is difficult to estimate the influence of the programme in the wider utilisation of PV systems within the business and industrial sector at present.

End users also expect electricity utilities to provide a quality service. In the case of placing PV systems on business and industrial buildings, the relationship between the end user and electricity supply companies is still likely to be important, especially if electricity is exported to the grid and imported to meet demand if shortfalls in supply occur. In this situation, electricity suppliers will expect a quality supply of electricity from local small-scale generators, and the generators will expect a quality service from the electricity supplier. As raised in Section 7.7.4, grid-connected PV will involve the electricity supplier to become a 'manager' of the balance between supply and demand. This relationship between electricity suppliers and local small-scale generators has worked in other countries. One example is the Nieuwland development at Amersfoort in the Netherlands where the energy supplier has placed PV panels on the roofs of suitable houses to generate electricity. The electricity supplier oversees the management of electricity supply and demand and the maintenance and operation of the PV systems. In return for the use of people's roofs, the supplier buys back the electricity at a competitive price. After the first ten years of operation, the ownership of the roof and the PV system returns to the owner of the building (Leeman, 2004).

Although PV systems have significant environmental benefits associated with a readily available, carbon neutral renewable source of energy, certain environmental issues have to be addressed. Placing PV panels on the roofs of existing buildings is likely to raise environmental concerns, particularly relating to the visual impacts of the panels. PV panels can either be placed directly onto existing roofs or individual PV cells can be integrated with existing tiles. Integrating PV cells with existing roofing materials can be problematic due to the existing configuration, shape and colour of roof tiles. In Sheffield, it has been estimated that the majority of roofs are grey (Brown et al, 2001). Although PV cells could be manufactured in grey, effective integration/design techniques are also needed to ensure that any additional visual impacts can be minimised.

7.8 Additional Issues

7.8.1 Planning Issues

PV panels can either be incorporated into the design of new buildings or added to existing buildings. It is unlikely that planning issues will arise for new build as the planning application for the new development will include the PV system. Incorporating PV into the façade cladding of an existing building, onto roof tiles or onto free-standing frames is likely to alter the character or roof slope of a building. Under the Town and Country Planning Act 1990, such developments will generally require planning permission. If the roof to be developed fronts a highway, planning permission is required (ODPM, 1995).

When considering PV planning permission applications, the interpretation of existing planning legislation and policy by local planning authorities may vary across the UK due to the size, scale and wide variety of PV systems available and the diversity of local environmental conditions. The main environmental impact of PV panels is visual intrusion, although this can be reduced to a minimum if suitably designed. In addition, local environmental constraints such as the historical status and the location of the building will influence planning decisions. Any proposals to install PV systems on Listed Buildings, within the grounds of a Listed Building or in designated areas like National Parks, are likely to require planning permission (GPDO, 1995). In a broader context, the proposed replacement of PPG22 by PPS22 and the publication of additional guidance, suggests that Local Authorities will be more likely to encourage renewable energy developments rather than limit them.

7.8.2 Legal Issues

The connection of PV systems to the national grid via the local electricity network is a new issue facing electricity utilities in the UK. As the grid-connection of PV systems will have an effect on the performance of the network, it is necessary for the PV systems to comply with any technical regulations specified by the electricity supplier in line with the Transmission and Distribution Codes (Terence O'Rourke plc, 1998). Specifically, the electricity supplier is likely to require that the quality of the power exported to the grid is acceptable and that the PV system can be shut down automatically in the event of a loss of mains power (Max Fordham and Partners, 1999). However, grid-connection of PV systems is largely unregulated. The lack of demand for grid connecting PV systems has meant that specific regulations for PV systems have not been developed. As such, technical variations are likely to occur between electricity suppliers. This lack of standardised regulations for grid-connected PV has resulted in engineering recommendations being used for the grid connection of PV (ESRU, 2000). Average owners and occupiers of buildings may find the recommendations complicated to understand and apply (ESRU, 2000).

Aside from the legal issues raised through lack of regulation, the issue of solar access may become a legal issue for some PV system owners. Solar access of PV panels may become restricted when parts of one property, such as plants, chimneys or surrounding objects like trees, cause shading on the PV panels of an adjacent building, therefore reducing their electrical output and system performance (Cassedy and Grossman, 1998). Whilst small soft shadows are not a problem, large dark shadows will reduce the electrical output of the panels (Sick and Erge, 1996). Overshadowing is likely to be a problem when retrofitting existing buildings as surrounding objects cannot be moved. With new build, the orientation of the building can be controlled and any potential shadowing from surrounding objects can be minimised by careful design and positioning.

7.9 Key Challenges for PV

This analysis has highlighted the range of issues facing the deployment of PV in buildings in Sheffield. As summarised in Table 7.2, PV offers a reliable source of energy. However, its utilisation faces problems in relation to end user expectations of accessibility, ease of use, convenience, consistency and affordability. In addition, PV only partially meets end user expectations of flexibility and quality and there are

Table 7.2 Current Evaluation of PV against End User Expectations

End User Expectations	Existing Energy System	PV
Accessibility	●●●	●
Ease of use	●●●	●
Flexibility	●●●	●●
Convenience	●●●	●
Reliability:		
Now	●●	●●
In the future	●	●●●
Consistency	●●●	●
Acceptability, in terms of:		
Affordability	●●	●
Quality	●●	●●
Cultural values, in particular:		
Environmental concerns	●	●●
Sustainability	●	●●

Key to symbols:
- ● Does not meet expectations
- ●● Expectations are partially met
- ●●● Meets expectations

questions raised over the environmental and sustainability implications of using PV in urban areas. From this examination, it is clear that a diverse range of obstacles face the wider deployment of PV in Sheffield, as summarised in Table 7.3. There is a lack of supporting infrastructure surrounding the introduction, promotion, installation, operation and maintenance of PV panels. In addition, the use of PV in urban areas raises issues surrounding the management of supply and demand and roof ownership issues. The obstacles facing PV, contained in Table 7.3, are subdivided into three stages of implementation, namely the introduction and promotion of PV, the installation of PV panels, and the operation and maintenance of PV panels. It is important to note that some of the obstacles raised in Table 7.3 overlap and may affect more than one stage of development. The obstacles raised here will be addressed alongside other renewable energy technologies relevant to Sheffield in Chapter 13.

Table 7.3 Obstacles Facing the Deployment of PV in Sheffield

End User Expectations and Additional Issues	Obstacles	Introduction & Promotion of PV	Installation of PV	Operation & Maintenance of PV
Accessibility	Access to information and advice	■		
	The decision on whether or not PV will be introduced through new build and/or retrofitting or refurbishing existing buildings	■		
Ease of Use	Limited infrastructure in place to promote, sell, install and maintain PV systems in buildings	■	■	■
	End user unfamiliarity with PV	■	■	■
	Persuading end users to become local electricity generators	■		
Flexibility	Matching the supply of PV electricity supply to demand will have storage and cost implications	■	■	■
	Electricity companies will need to become electricity "managers" who manage supply and demand and buy and sell electricity to/from local generators/end users	■		■
Convenience	Inconvenience and disruption caused by adding PV panels to existing buildings		■	
Reliability	End user confidence in PV technology and electricity supply	■	■	■
	End user understanding of the PV system			■
Consistency	Ownership of roof and roof space issues. This has installation, operation, maintenance, cost and insurance implications.	■	■	■
Acceptability	Cost of PV systems	■		
	Quality of supply from consumers to electricity utilities and vice versa			■
	Electricity companies will need to manage the balance of supply and demand			■
Planning Issues	Visual impacts of PV panels on roofs and/or façades of buildings	■	■	
Legal Issues	Compliance with technical regulations specified by the electricity utility		■	
	Solar access of PV panels e.g. overshadowing	■	■	■

Key to symbol: ■ Obstacle affects this stage of deployment.

8. WIND POWER

8.1 Utilising the Wind

Humans have harnessed the power of the wind for many centuries. Traditionally, windmills have converted the energy from the wind into mechanical power to pump water or grind grain (ICLEI, 2000c). Modern wind turbines can provide mechanical power, although they are more commonly used to generate electricity. Wind power is the second largest available renewable energy resource in Sheffield. Wind power could provide an estimated 2,808 TJ of electricity per year, which could be utilised for electrical applications within any sector. By utilising the wind power resource in Sheffield, it can be estimated that local annual carbon emissions could be reduced by 105,000 tC (Appendix B and D). Although this resource is available in Sheffield, it is significantly under-utilised at present. In order to find out why this situation exists, the technical, economic, non-technical and non-economic issues facing wind power need further investigation.

In order to address these issues, the chapter has been subdivided into two parts. The first part (Sections 8.2 to 8.6) reviews wind power in the broad context of the UK. The basic aspects of wind power are introduced in Section 8.2. The resource considerations (Section 8.3) and applications (Section 8.4) are then discussed. The technical and economic status of wind power is explored in Sections 8.5 and 8.6, respectively. The second part of the chapter examines stakeholder expectations of energy services and highlights the differences between wind power and conventional energy technologies in delivering consumers with electricity. This examination provides the basis for identifying obstacles which currently face the deployment of wind power in Sheffield. Using the relevant stakeholder demand criteria as a basis for the analysis, wind power is evaluated in Section 8.7. Any additional issues facing wind power are examined in Section 8.8. In Section 8.9, the key challenges facing wind power are raised. This section firstly summarises how wind power performs in relation to stakeholder expectations before looking at the obstacles that specifically influence the deployment of wind power in Sheffield.

8.2 Basic Aspects

The majority of wind turbines in the UK have 2 or 3 blades mounted on a horizontal axis, although vertical axis wind turbines are also available. The turbines are mechanical devices comprising of rotor blades, a tower and a nacelle which holds the gearbox and generator. Using aerodynamic forces and rotating shafts, the turbines convert the energy in moving air into a useful power source (ETSU, 1999). Wind turbines are available in a range of power units and sizes. A single wind turbine can supply power from a few hundred watts to several megawatts. Small 100 W turbines can be used on single homes and cottages with large 2 megawatts (MW) turbines used for commercial applications. To increase the power output, wind turbines can be grouped together in clusters or wind farms. In the UK, wind farms typically contain 20 wind turbines (ETSU, 1999). Single turbines or wind farms can be constructed on and offshore. Any site used for wind power generation must be easily accessible for maintenance and repair work. The turbines are controlled by remote control systems and can be stopped during high winds or emergencies (Powergen Renewables Ltd, 2001).

The expected energy consumption and peak power demands of the application determine the power unit and number of wind turbines. For electrical power generation, the electricity supply must coincide with demand. The amount of electricity produced by wind turbines depends on the wind speed and the power is generated according to the cube of wind speed (Jackson and Löfstedt, 1998). Low wind speeds generate proportionally less electricity than higher wind speeds. As such, the amount of electricity generated by turbines is subject to fluctuations in wind speed. Using storage facilities increases the reliability of the electricity supply from wind turbines. Electrical power from wind turbines can be stored in batteries, pumped storage or supplied directly onto the national grid. Batteries can provide a simple and economic option for remote areas where demand is low and storage is limited (Anon, 2000c). Batteries also require minimum maintenance, as they have no moving parts. Pumped storage facilities use the power from the wind to pump water up into a holding reservoir. When the energy is required, the water is allowed to flow down, powering a standby power station (Anon, 2000c). As an alternative to on-site storage, wind turbines can be connected to the national grid. At the point of connection with the network, the electricity from the turbines is usually metered to record supply. Although one-way meters which record the amount of electricity consumed by a building are the most common, there are also two-way metering systems available which can record outgoing and incoming electricity supply.

8.3 Resource Considerations

Wind power is an intermittent resource due to the dispersed and variable nature of the wind (ICLEI, 2000c). The wind resource in an area is determined by a number of factors including local wind speeds, which generally increase with elevation and the availability of land for wind power generation (ICLEI, 2000c). Wind power is not expected to be economically viable where average wind speed is less than 7.0 metres per second (m/s) (ETSU, 1999). In the UK, calculations have showed that 33% of the land area in England, Wales and Scotland and 4% of the land area in Northern Ireland has an annual mean wind speed of, or over, 7.0 m/s (ETSU, 1999). Whilst windy areas provide a potential energy source, wind turbines are sensitive to excessive, gusty winds and need to be protected against storms and high winds. The availability of land is an important consideration. Whilst the base of each wind turbine and access tracks only take up a small percentage of available land, the turbines must be spaced between 5-10 rotor diameters apart to reduce the level of turbulence between the turbines (ETSU, 1999). As such, the wind farms must be arranged so that the turbines do not "shadow" one another (BWEA, 2000). Physical constraints such as built up areas, forestry and local designations affect the siting of wind turbines onshore.

The offshore wind power resource is potentially greater than on land. However, harsher climatic conditions are an important consideration for wind turbine construction and operation. Increased emphasis is placed on the technical aspects of turbine design and the construction of the foundations (ETSU, 1999). The offshore wind power resource is constrained by working water depths, accessibility of the turbines, the use of the coastline for other activities and the capacity of the onshore electrical network (ETSU, 1999). Local designations such as coastal nature reserves may affect the siting of the turbines offshore.

8.4 Applications

The majority of wind turbines in the UK are used to generate electricity. Wind turbines can meet the electricity demands of a wide range of stakeholders as illustrated in the following examples:

- County Durham - A wind turbine at Cassop Primary School produces 270 kWh per day of electricity, which is twice the school's electricity requirement. The surplus electricity is exported to grid via an import/export meter (DTI, 2001e)

- East Kilbride, Scotland - A 600 kW wind turbine provides 35-40% of energy required by Sainsbury's Supermarket distribution depot (DTI, 2000c)

- Great Yarmouth - A 1.5 MW wind turbine provides 4,000 households or 5% of Great Yarmouth's domestic electricity requirements (Anon, 2000c).

- Royd Moor, Penistone, South Yorkshire - This wind farm contains 13 turbines and has a total generating capacity of 6.5 MW. The electricity is fed directly onto the national grid (Powergen Renewables Ltd, 2001).

- Blyth Harbour on the Northumberland coast - This is the UK's first offshore wind power project. Two turbines, each providing 2 MW of electricity, power 3,000 households annually (Anon, 2000d).

- Redcar in Teeside in the North East – Planning permission has recently been given to develop an 18 turbine wind farm on an urban industrial brown field. This project has been named the TeesWind project (AMEC, 2004a and AMEC, 2004b).

- London - A single turbine situated on the South Bank near the Royal Festival Hall in London was erected to provide power for the "Shell Electric Storm" event, which ran from November 2003 to February 2004 (RES, 2004). The turbine continues to generate electricity.

8.5 Technical Status

Wind power technology is well established with more than 8,000 MW of wind power installed worldwide (ETSU, 1999). Modern wind turbines are designed to last for 15-25 years and better designs have increased the efficiency and reliability of turbines whilst reducing costs. New machines are being developed which are 96% reliable (EUROPA, 2001). Technical developments have also been made towards increasing public acceptance of wind turbines. In particular, refinements in the design of turbines has led to greater efficiency and reduced noise levels, as in, for example, the Ecotricity turbine installed at the Ecotech Centre in Swaffham, Norfolk (Anon, 1999a). The noise of the mechanical parts in this turbine has been reduced and the design has been refined to reduce the visual scale of the turbine (Anon, 1999a). Additionally, higher energy yields have been achieved through small increases in the height of the tower and length of the blades (Powergen Renewables Ltd, 2001). Advances have been made in offshore wind technology with designs aimed towards increasing energy output and reducing maintenance costs (Anon, 2000c). Further research has been directed towards using new lightweight materials for turbine blades, devising control systems to allow operation of large blades in storms, developing alternative electricity storage using compressed air storage and exploiting the offshore wind power resource (ICLEI, 2000c).

8.6 Economic Status

Wind turbine projects are capital intensive. The capital costs of wind turbines can amount to 75-90% of the total cost (BWEA, 2000). Table 8.1 illustrates the cost breakdown for installing a 600 kW wind turbine.

Table 8.1 Average Costs Incurred for Installing a 600 kW Wind Turbine (ETSU, 1999)

Capital costs	£	Annual costs	£
Ex-factory cost	285,000	Operation & maintenance	9,000
Commissioning & installation	45,000	Local rates	3,843
Civil engineering	45,000	Land rental	2,000
Electrical engineering	75,000	Insurance	2,700
Miscellaneous (including development, planning permission and financing costs)	30,000	Reactive power charges	1,400
Total installed cost	480,000	Total annual cost	18,493

As the majority of wind turbines in the UK are used for electricity production, the price of electricity per kWh from wind power is an important concern. The unit cost of electricity produced from wind power is influenced by a number of factors, namely wind speed, the performance of the turbine, the initial capital outlay, the running costs of the turbine and current electricity prices. Between 1990 and 2000, wind projects were supported through the Non Fossil Fuel Obligation (NFFO) in England, Wales and Northern Ireland and the Scottish Renewable Orders (SRO) in Scotland. The NFFO was introduced by the government to encourage renewable energy use in the UK. Regional electricity companies were obliged to purchase a percentage of their electricity supply from renewable energy sources (Shaw, 1999). Under NFFO, each renewable energy project received a financial subsidy, which stimulated their commercial success and ability to compete in the energy market. In Table 8.2, the price of electricity generated by wind turbines under the NFFO scheme and fossil fuel sources are compared. There were five NFFO programmes with NFFO1 being the first projects commissioned under the scheme and NFFO5 being the last group of projects.

From the comparison illustrated in Table 8.2, cheaper electricity is produced from large-scale wind farms. Under these circumstances, electricity generated from wind power is competitive with new coal fired plants. The generation of electricity from wind turbines has a number of benefits over fossil fuels sources. In particular, wind is a vast, free resource and the extraction of energy from the wind does not contribute to air pollution unlike electricity generation from fossil fuel sources. However, the environmental costs of electricity production from fossil fuel sources are not reflected in current electricity prices.

Table 8.2 Comparison of Electricity Prices from Different Energy Sources (BWEA, 2000 and DTI, 1998)

Energy Source	Pence per kWh (p/kWh)	Average p/kWh
Wind power - average NFFO5 price, large projects	2.43 - 3.10	2.88
Wind power - average NFFO5 price, small projects	3.4 - 4.6	4.18
New combined cycle gas plant	1.8 - 2.2	
New coal fired plants	2.6 - 3.25	
Existing coal fired plants (including cost of retrofitting flue gas desulphurisation)	Around 2.0	

In April 2002, the Renewables Obligations replaced the NFFO scheme (Ecofys BV, 2001). Under the Renewables Obligation, licensed electricity companies must source a specified amount of their total sales from renewable energy sources. In 2002/3, the Renewables Obligation started at 3% and will rise to 10.4% by 2010/11 (Ofgem, 2004a). This intervention into the energy market by the Government and Ofgem, who regulate the gas and electricity market in Britain, has helped to stimulate a market for renewable energy, which will continue to grow as the Renewables Obligation increases. Each year, licensed electricity suppliers must produce Renewables Obligation Certificates (ROCs) in England, Wales and Northern Ireland or Scottish Renewable Obligation Certificates (SROCs) in Scotland to prove to Ofgem that they are complying with the Renewables Obligations. Each ROC is equal to 1 MWh of electricity and show that the electricity has been produced from renewable energy sources and supplied to end users in Great Britain (Ofgem, 2004b). Instead of the certificates, electricity suppliers can also make a buy-out payment, which has been set at £31.39 per MWh for 2004/5, or a combination of both options (Ofgem, 2004b).

In addition to the changes in electricity supply, there have also been regulations placed on business and industrial end uses. In April 2001, an energy tax was placed on electricity and natural gas consumed by the business and industrial sector. This energy tax was introduced through the Climate Change Levy. By switching their energy supply to green power, business energy users can claim exemption from the Levy. Levy Exemption Certificates provide proof that the electricity is produced from renewable energy sources and supplied by UK based generators (Greenprices, 2004a). Both the Renewables Obligation and the Climate Change Levy have created a favourable market for renewable energy developments, including the exploitation of wind power.

It is widely believed that the future prospects for wind power are good. Investment in wind power is directed towards producing more efficient and reliable designs and increasing public support of wind power projects. At present, technological improvements and economies of scale are reducing the costs of turbines and their components. More electricity can be produced from cost-effective machines (BWEA, 2000). As technical improvements are increasing the performance of wind turbines, it is likely that costs will continue to fall. It has been suggested that continued reductions will lead to the cost of energy from wind power being 75% of its 1996 cost by 2010 and to 70% of its 1996 cost by 2025 (ETSU, 1999). Additionally, the intervention and regulation into the supply and demand of electricity in the UK by the government and Ofgem has opened up the energy market for competition between renewable and non renewable energy sources. Also, if recent rises in domestic electricity and natural gas prices continue, this may stimulate more investment in renewable energy and increase competition between different electricity sources. With increased demand for renewable electricity, there are concerns that there will be a shortage in supply (Greenprices, 2004b). Already, organisations such as British Telecom, who are a major electricity consumer in the UK, are planning to invest in their own production capacity and are turning to wind power and solar energy technologies for the answer (Greenprices, 2004b).

8.7 Meeting Stakeholder Expectations

8.7.1 Wind Power and Energy Suppliers

In addition to the technical and economic issues raised above, wind power must also meet the expectations of stakeholders. Within Sheffield, wind turbines are more likely to be grid connected as not all potential wind power sites are directly adjacent to electricity users. Additionally, feeding electricity directly onto the national grid will reduce electricity storage costs. In this situation, the main investors in wind-generated electricity are likely to be licensed electricity companies rather than the end users of electricity, such as domestic users.

As examined in Section 8.6, licensed electricity suppliers have to purchase a specified amount of their electricity from renewable energy sources. As such, wind-generated electricity is likely to be attractive to electricity suppliers as it can help them meet their Renewables Obligations. In order for electricity suppliers to buy electricity from wind power developments in Sheffield, the electricity supply must meet the expectations of electricity suppliers.

8.7.2 Accessibility

If electricity companies are to invest in wind power, they will want to know how accessible the supply of wind is in Sheffield. Although wind power has considerable potential in Sheffield, it is not fully exploited at present, which raises questions concerning the accessibility of the resource and its subsequent exploitation. The MIRE renewable energy study identified a number of key sites within Sheffield's built environment which have wind speeds of between 5.3-9.0 m/s (Grant et al, 1994c and Elsayed et al, 1996). The locations of these sites are shown in Figure 8.1. At each site, one, or in some cases two, 500 kW wind turbines could be installed. In addition to sites being located within the urban settlement of Sheffield, the MIRE study also identified some of sites which are located within or near to the Peak District National Park. This rural hinterland to the west of the city is under control of the Peak District National Park Authority, which acts as the planning authority for the whole of the Peak District National Park, whereas the urban conurbation of Sheffield is administered by Sheffield City Council. As Sheffield is under the control of more than one authority, this has had major implications on the exploitation and integration of renewable energy technologies, including wind turbines, within the district (Kellett, 1994b). Additionally,

Figure 8.1 Proposed Wind Power Sites in Sheffield

mm

proposing wind developments within the Peak Park is problematic as there are strict planning controls and any proposed wind power developments are likely to face public opposition from residents and tourists. However, although commercial wind farm development may be opposed, some opportunities may exist for single turbines to be erected (Grant et al, 1994c).

In addition to the exploitation of wind power in the rural hinterland of Sheffield, there are also potential sites within close proximity of the built-up area, as shown in Figure 8.1. Whilst these sites are not located in the Peak Park, their accessibility faces different constraints such as pressures on urban land use, proximity to residential properties, location within the green belt and dealing with visual impacts. One current pressure on urban land use is the growing need to build residential properties (ODPM, 2004a). This increased competition for available land could have implications on the utilisation of identified sites in Sheffield with a good wind power resource. This raises the issue of problems with the possible allocation of renewable energy exploitation sites within local authority plans. If cities are to become responsible for their carbon emissions, it may be necessary to allocate land for energy purposes within the district boundary.

Many of the potential wind power resource sites in Sheffield are located on green belt land. This raises concerns over whether wind power developments will be acceptable within the green belt. Green belt designations exist in order to contain the city, prevent neighbouring towns from merging into one another, and safeguard the countryside from encroachment and to assist in urban regeneration by encouraging the use of brownfield sites within the district boundary (ODPM, 2004b). Additionally, as wind power developments are not rural in character, it is debatable that such developments would be acceptable on green belt land (ODPM, 2003).

If, in order to achieve sustainable urban energy systems within cities, Sheffield becomes responsible for lowering its carbon emissions, this will have implications on the relationship between the Peak District National Park Authority and Sheffield City Council. Whilst there is a need to move towards energy efficiency to lower energy consumption and utilise renewable energy sources to lower carbon emissions, there is also a need to conserve designated landscapes like the Peak Park. Reducing carbon emissions locally implies that in a district such as Sheffield, the rural and urban authorities will have to address local renewable energy exploitation issues jointly. Whilst wind may not be acceptable in the Peak Park, less visible renewable energy technologies may be. In addition to these issues, placing wind turbines within urban areas means that local residents in Sheffield will have to deal with the environmental impacts of local electricity generation directly. These issues will be examined in more detail subsequently in Section 8.7.8.

8.7.3 Flexibility

Electricity from wind power can only be flexible if supply matches demand. Unlike solar energy, wind is available at any time of the day or night, although it is important to remember that it is an intermittent resource. Although sites have been identified which have suitable average wind speeds for wind power developments in Sheffield, there will be some occasions when the wind does not blow. This raises two key issues; firstly, the need for electricity storage and, secondly, the need for a back-up supply. As examined in Section 8.2, electricity can be stored in batteries, in pumped storage or shipped to supply demand via the national grid. Battery storage is expensive and may be an unsuitable form of storage for electricity suppliers. Using pumped storage as an option will require a suitable location to be identified and developed. Feeding electricity onto the national grid acts as a kind of 'virtual storage.' Although the electricity is used to meet demand elsewhere, electricity can be taken from the grid in exchange for electricity supplied from wind turbines. This system is common practice and is therefore more familiar to electricity suppliers. When the wind fails to supply adequate electricity supply, alternative electricity supplies may be needed depending on the current level of demand. This will have implications for the management of the electricity system by electricity suppliers.

8.7.4 Reliability

In order for wind power to be considered as an alternative to conventional electricity supplies, the energy supply and technology both need to be reliable. Although wind is a free, carbon neutral energy source, which can be predicted using wind speed data software packages, electricity suppliers and other potential investors in wind power need to be confident that a particular site will deliver a given amount of energy supply over a particular period. In essence, the location of the wind turbine directly influences its performance and the feasibility of a wind power development. If electricity suppliers are to invest in wind power, they need to be re-assured that wind turbines will deliver what they are specified to deliver. In particular, electricity suppliers will need guarantees that the turbine is produced installed and operated correctly to perform in accordance with their requirements. When designing and constructing turbines, it is important that the turbine is reliable and performs according to its specifications. This raises the issue of the need for guarantees to be placed on the materials used and the manufacture and installation of wind turbines.

8.7.5 Acceptability

Investing in local wind-generated electricity supply will help electricity suppliers meet their Renewables Obligations. As examined in Section 8.6, electricity suppliers must purchase a percentage of their electricity from renewable energy sources as set out by the Renewables Obligation. If the wind power resource in Sheffield is going to be utilised to meet this Obligation, the supply of electricity must be of a certain quality. In particular, electricity supply must meet frequency and fluctuation specifications. The connection of single or multiple wind turbines to the grid would require the turbines to comply with any technical regulations as specified by the electricity supplier in accordance with transmissions and distribution codes (Terence O'Rourke plc, 1998).

8.8 Additional Issues

8.8.1 Planning Issues

Under the Town and Country Planning Act 1990, most forms of development require planning permission (HMSO, 1990). Land designations may affect the siting of turbines, particularly if potential sites are located within green belt land, on locally designated land and within the Peak District National Park. Any wind power development will require a power line to be installed to the nearest suitable electricity sub-station or other point of connection in the local distribution network. Electrical grid connection is normally subject to an assessment and planning application (BWEA, 1994). Best Practice Guidelines for Wind Energy Developments recommend that this work is planned in line with the developer, the local electricity company, the planning authority, affected land owners and relevant consultees (BWEA, 1994).

In relation to wind power developments, specifically, and renewable energy developments, generally, the planning system has been viewed as a barrier to the success of developments (DTI, 2003a). In particular, the lack of precedent in this area, limited awareness and guidance, and lack of information has been a problem. A lack of precedent helps to create uncertainty amongst key decision-makers. Although

Planning Policy Guidance (PPG) Note 22 on renewable energy, published in 1992, set out the Government's national stance on renewable energy developments, it has been criticised as lacking in clarity, focus and policy direction (Gill, 2004 and Kelly and Evans, 2004). With the new draft Planning Policy Statement (PPS) 22 is set to supersede PPG22 (ODPM, 2003a), it is hoped that this document will provide more guidance and support for developers and will encourage Local Authorities to become more pro-active in supporting local renewable energy developments (BWEA, 2003).

8.8.2 Convenience Issues

The installation of wind turbines in Sheffield may initially be regarded as inconvenient by local people due to the building work involved during the construction period. However, once this initial period has passed, locally generated electricity can be regarded as convenient as it can provide additional security if shortfalls in supply occur and can help to diversity electricity generation capacity in the UK.

8.8.3 Community Investment and Ownership

Placing wind turbines in urban areas may stimulate urban communities to invest in wind power. Although community ownership of urban wind turbines has yet to be tested in the UK, there have been some successful rural schemes such as the Gwmni Gwynt Teg in Wales (Yes2wind, 2004). Additionally, having local wind turbines may attract greater consumer investment in green electricity, as consumers may perceive the turbines to be the visual proof of their investment. This could act as a catalyst for increased public support of renewable energy developments and renewable electricity purchasing.

8.8.4 Local Environmental Considerations

Although it is accepted that wind power is a carbon neutral renewable energy source, there are some local environmental considerations which must be addressed. Wind power projects have received a lot of public attention and often opposition. Common issues of concern include noise, visual impact, impacts on wildlife, shadow flicker, land use, interference with electromagnetic signals, safety issues, vandalism and access. Each of these issues could occur in Sheffield, as outlined below:

- Noise - When the turbine blades move through the air this can create a continuous whirring noise. The extent to which this noise will be an issue depends on the site, the local topography, local weather conditions, the position of the turbine and its proximity to receptors such as people and buildings,

- Visual Impact - The physical presence of a single or group of wind turbines has a visual impact on a landscape. In particular the size, number, grouping, design and colour of the turbines, the type of landscape and the size and location of the local population are important considerations facing the siting of wind turbines (ETSU, 1999). However, it is important to recognise that in some urban contexts, such as areas with a traditional manufacturing and industrial base, the presence of one or more wind turbines may not be visually intrusive (Elsayed et al, 1996),

- Wildlife - Studies have highlighted that the siting of wind turbines can disturb wildlife, especially migratory bird patterns. Unfamiliarity with wind turbine sites could disturb the behaviour of birds and may result in bird mortality (ETSU, 1999),

- Shadow Flicker – As the sun shines on wind turbines, the shadows from the rotating blades can cause a stroboscopic effect, called "shadow flicker" (Kellett, 1990). This could have an adverse effect on people within close proximity to the turbines or on people at greater distances at certain times of the day, such as sunrise and sunset,

- Land Use – As discussed in Section 8.7.2, pressures on land use within Sheffield and other urban areas affects the utilisation of potential sites for wind power developments. In rural parts of Sheffield, the location of wind turbines near or in a designated green belt or in local or nationally designated areas could be problematic. The land around or between wind turbines could be used for many different purposes including grazing animals, growing crops or for bio-diverse natural environments. In urban areas, close proximity to residential estates may be an issue,

- Electromagnetic Interference - The operation of wind turbines can interfere with electromagnetic signals as the rotation of the blades can scatter signals and reduce the quality of signal reception (Powergen Renewables Ltd, 2001),

- Safety Issues - Safety issues are an important concern for the design, construction and decommissioning of all developments. With wind turbines in particular, the aerodynamic design of the blades allows the blades to "fly" through the air. Detached blades could place the public in danger. Although there have been instances where this has happened, it is a very rare occurrence. Additionally, "ice throw" from blades could be a problem during colder months (Kellett, 1990),

- Vandalism - Locating wind turbines in inner city areas may attract vandalism, particularly if the designation site has been subject to vandalism on previous occasions (Elsayed et al, 1996). Vandalism could include attempted damage to ground-based equipment and to blades from throwing stones and other projectiles, and

- Access - Access to the site is an essential part of wind power developments. For routine maintenance and occasional repairs, easy access to the site is needed. Using existing routes to the site will increase the site's accessibility and minimise the need for additional work in constructing access routes.

8.9 Key Challenges for Wind Power

This examination has demonstrated that the technical and economic status of wind power have good prospects. Advances in wind power technology have created more efficient, reliable and quieter turbines with larger power outputs. Economies of scale have lowered the capital costs of wind turbines, therefore increasing the competitiveness of wind-generated electricity. However, in order for wind power to be purchased by electricity suppliers, it must also meet their expectations. The performance of wind power against the expectations of energy suppliers is summarised in Table 8.3.

As summarised in Table 8.3, the main problem facing wind power in Sheffield is the accessibility of the resource. However, in terms of flexibility, reliability and acceptability, wind power competes with non renewable-generated electricity. Placing wind turbines in Sheffield also means that the local community has to deal with impacts associated with local electricity generation. Therefore, wider issues of planning, inconvenience, community investment and ownership issues and local environmental considerations, also face the deployment of wind power within the district. These

Table 8.3 Current Evaluation of Wind Power against the Expectations of Energy Suppliers Companies and Existing Energy Systems

Energy Supplier Expectations	Existing Energy Systems	Wind Power
Accessibility	••	•
Flexibility	•••	•••
Reliability: Now In the future	 •• •	 •• •••
Acceptability, in terms of: Affordability Quality Environment Sustainability	 •• •• • •	 •• •• •• ••

Key to symbols:
- • Does not meet expectations
- •• Expectations are partially met
- ••• Meets expectations

issues or obstacles facing wind power in Sheffield are summarised in Table 8.4, which simplifies and summarises the analysis carried out in Sections 8.7 and 8.8. In Table 8.4, the obstacles are sub-divided according to the expectations of electricity suppliers, wider community issues and at what stage of deployment they will affect the utilisation of wind turbines in Sheffield. The deployment of wind power in Sheffield can be split into two key phases; firstly, the wind turbine proposal and secondly, the installation and operation of the development. It is important to note that some of the obstacles raised in Table 8.4 overlap and will affect more that one phase of deployment. The obstacles raised in Table 8.4 will be addressed alongside other renewable energy technologies relevant to Sheffield in Chapter 13.

Table 8.4 Obstacles Facing the Deployment of Wind Power in Sheffield

Energy Supplier Expectations and Additional Issues	Obstacles	Wind Power Proposal	Installation and Operation
Accessibility	Location of potential wind power sites within the green belt, with local designations and within the Peak District National Park	■	
	Pressures on urban land use		■
	No land allocation energy purpose within local plans	■	
Flexibility	Need to match supply with demand. This has storage and cost implications		■
Reliability	Confidence that the site will deliver a reliable electricity supply	■	
	Energy supplier confidence in wind turbine technology, its installation and operation	■	■
Acceptability	Wind power development needs to be certified under the Renewables Obligations	■	
	Electricity supply must meet frequency and fluctuation specifications as laid out by the electricity company		■
Planning Issues	Need for local authorities to become more pro-active in encouraging and supporting local wind power developments	■	
Convenience Issues	Inconvenience caused by building work when installing turbines		■
Community Investment & Ownership	Changes to traditional system of electricity generation and supply which can have positive and negative impacts within a community	■	
Local Environmental Considerations	The move towards local generation will mean that local communities will be required to manage & mitigate any adverse environmental impacts associated with the energy development		■

Key to symbol: ■ The obstacle affects this stage of deployment

9. BIOMASS ENERGY

9.1 Utilising Plants for Energy

During photosynthesis, green plants convert solar energy into chemical bonds including carbon and hydrogen. The solar energy stored in biomass or plant matter, can be extracted and converted into useful forms of energy including heat and power. Solar energy can be recovered from any land and aquatic plant and organic waste. Biomass is the third largest renewable energy resource available in Sheffield (Chapter 4 and Appendix B). By utilising local resources, biomass could provide Sheffield with an estimated 2,291 TJ of heat per year, which could be utilised for heating applications within any sector. Associated local carbon emissions could be reduced by around 33,450 tC (Appendix D). Although this resource exists in Sheffield, it is under-utilised at present. In order to investigate why this situation exists, it is necessary to investigate the technical and non-technical issues facing the utilisation of biomass energy in Sheffield.

In order to address these issues, the chapter has been subdivided into two parts. The first part (Sections 9.2 to 9.8) reviews biomass energy in the broad context of the UK. The basic aspects of biomass are introduced in Section 9.2, followed by resource considerations in Section 9.3. Ways of preparing biomass are then discussed (Section 9.4) followed by an examination of the technical status of conversion technologies (Section 9.5) and processing technologies (Section 9.6). The different types of output and applications are outlined in Section 9.7. Section 9.8 explores the economic status of biomass. The second part of the chapter examines stakeholder expectations of energy services and highlights the differences between biomass energy and conventional energy technologies in delivering energy to end users. This examination provides the basis for identifying obstacles which currently face the deployment of biomass in Sheffield. In Section 9.9, current and potential stakeholders are identified. Biomass energy is evaluated against their expectations, using the stakeholder demand criteria as a basis for the analysis. Additional issues facing biomass energy are examined in Section 9.10. In Section 9.11, the key challenges facing biomass energy are raised by firstly summarising how biomass energy performs in relation to stakeholder expectations, before looking at the specific obstacles which influence the deployment of biomass energy in Sheffield.

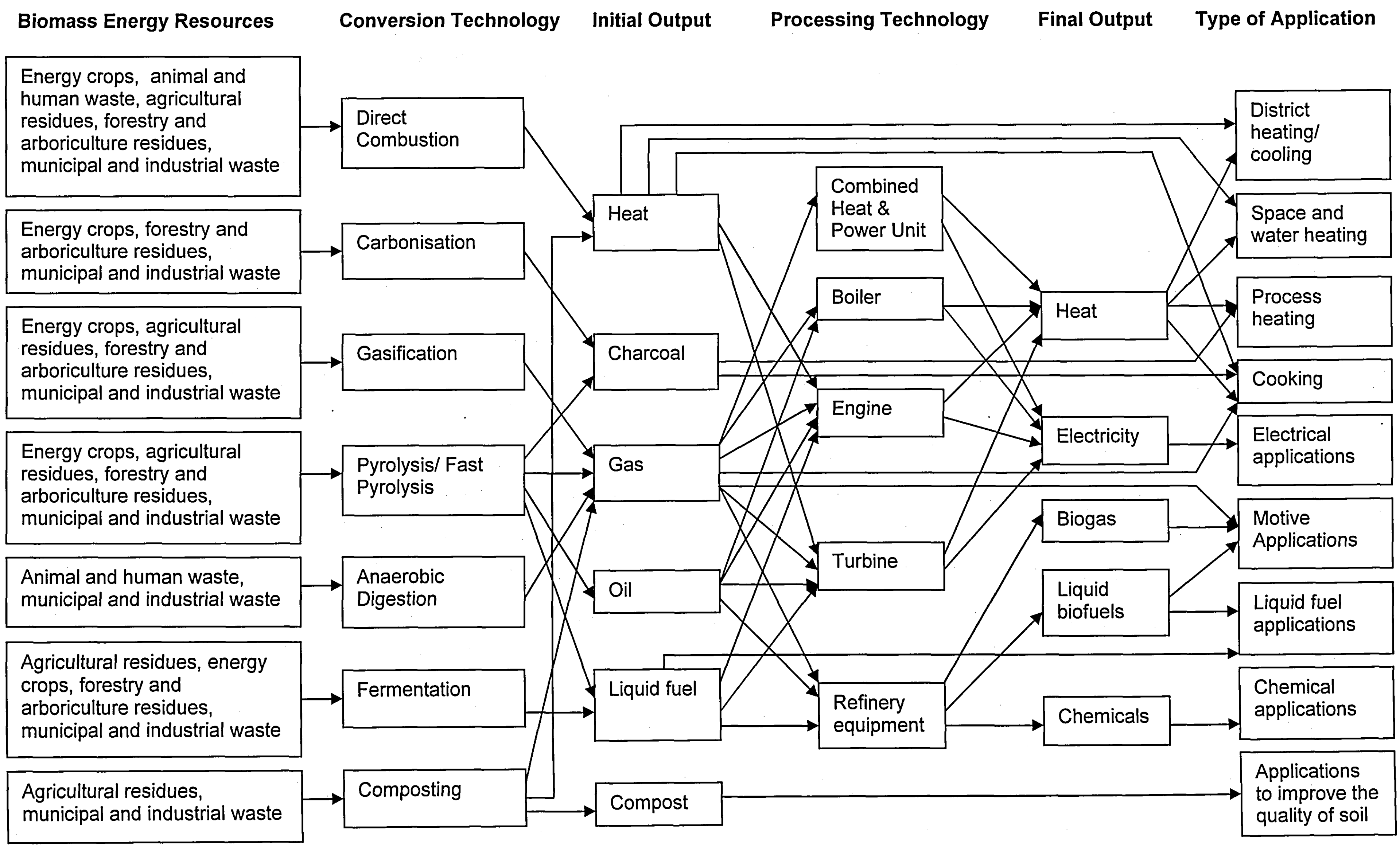
9.2 Basic Aspects

Biomass can be obtained from a wide range of sources. Crops can be grown specifically for energy conversion. Typically, these "energy crops" include a range of trees, grasses and plants, although crops used for food production such as potatoes could also be utilised. Energy can also be extracted from organic wastes obtained from animal husbandry practices, forestry and arboriculture operations and agriculture. Due to the diversity of plants and organic wastes that can be utilised for energy conversion purposes, biomass energy resources can be placed into the following categories:

- Energy crops,
- Animal and human waste,
- Agricultural residues,
- Forestry and arboriculture residues,
- Organic municipal and industrial waste.

Before the Industrial Revolution, energy requirements for heating, lighting and cooking were met by biomass, in particular wood fuel. During the Industrial Revolution, the widespread exploitation of fossil fuels replaced the use of biomass. Today, fossil fuels continue to meet modern energy and fuel needs. However, modern advances in energy conversion technologies have opened up opportunities for biomass to be co-fired with fossil fuels or used as an independent energy source. Modern applications of biomass can extend to include domestic and industrial cooling, electricity generation and liquid fuel for transportation purposes. Biomass can be burnt directly or converted into solid, liquid or gaseous fuels. Using the biomass energy categories above, Figure 9.1 illustrates the various pathways for the utilisation of biomass energy resources. The diversity of biomass resources that can be converted using modern conversion technologies is illustrated. Figure 9.1 shows that different biomass resources can be used in the same conversion technology for the same application. The range of initial outputs can either be used directly for various applications or can undergo further processing to produce electricity or refined fuels. Biomass energy can be used for a variety of applications ranging from supplying heat for individual rooms to whole districts, providing heat for industrial processing such as smelting, and for motive power and other liquid fuel applications. Further examination of the biomass resources, conversion technologies, processing technologies, initial and final outputs and applications featured in Figure 9.1 will take place over the following sections.

Figure 9.1 Pathways for the Utilisation of Biomass Energy Resources



9.3 Resource Considerations

9.3.1 Energy Crops

Energy crops are grown specifically for energy conversion purposes and cover of a wide range of crop types. The main crops that have been developed for use in energy conversion technologies are:

- Short rotation coppice (SRC) e.g. willow and poplar trees,
- Herbaceous crops e.g. miscanthus,
- Vegetable-oil bearing crops e.g. oilseed rape,
- Carbohydrate-rich plants e.g. saccharine plants, starchy plants and cellulose plants.

In Northern European climates, short rotation willow, poplar trees and miscanthus are the most common varieties used for energy conversion purposes (ETSU, 1999). Vegetable-oil bearing crops, such as oilseed rape and carbohydrate rich plants, could also be used. Once planted, energy crops are harvested on a regular basis. Some energy crops, in particular SRC, can be processed before being fed into the energy plant. SRC can be chipped using a chipper machine. This makes the fuel easier to handle, transport, store, dry, cool and burn (Shaw, 1999). Energy crops must be stored in well ventilated facilities to minimise the risk of rotting (Warburton et al, 1996). Drying the energy crops will ease the storage of the material and increase the energy content of the fuel. The energy content of a fuel is measured as the calorific value, which is the amount of heat released on complete combustion per unit weight of biomass (DTI, 2001a). The calorific value is influenced by the moisture content of the fuel. The lower the moisture content, the higher the calorific value and energy output. Energy crops tend to have low calorific values at around 19 gigajoules (GJ)/dry tonne (ETSU, 1999). When the moisture content of energy crops reaches 55%, the calorific value falls to 10 GJ/dry tonne. Energy crops have a low density of around 300 kilogram's per metre cubed (kg/m^3) when harvested which, after drying, can fall down to $150kg/m^3$. In comparison, coal has a calorific value of 27 GJ/tonne and a density of 800 kg/m^3 (ETSU, 1999).

Research and development has been directed towards improving the performance and reliability of existing growing and harvesting practices and reducing costs. In particular, work has been directed towards increasing the yield of energy crops, improving crop husbandry practices, and reducing the capital and investment costs involved in setting up projects. Advances have been made in increasing the dry yield of energy crops per hectare and developing varieties with greater disease resistance and fast growth rates, for example, willow hybrids (ETSU, 1999). In the UK in particular, pilot trails are been undertaken to develop experience in growing miscanthus, ready for future large-scale production (Anon, 2000e). Further research has been directed towards enhancing the breeding conditions of energy plants and improving their cost effectiveness (EUROPA, 2001).

The large-scale production of energy crops in the UK would require a significant amount of land. Before 1992, all agricultural land was designated for use for food production. In 1992, a policy was introduced in which 15% of productive agricultural land was designated for set-aside purposes (Shaw, 1999). Although set-aside land could be utilised for growing energy crops, the lack of demand for energy crops has limited their development. Sporadic markets have developed for particular projects such as the 10 MW ARBRE demonstration plant in North Yorkshire. Although the ARBRE plant is no longer functioning, the supplies of SRC for the plant are now being co-fired alongside coal at the Drax Power Station in Yorkshire (Gow, 2004). The financial viability of growing energy crops will benefit from large-scale production and economies of scale. At present, energy crop projects require a large amount of capital investment for crop establishment. When compared to subsidised food production on agricultural land, the growth of energy crops does not have the same financial returns (ETSU, 1999). Traditional uses of land, an uncertain future and investment risks affect all energy crop production.

9.3.2 Animal and Human Waste

Animal and human waste can be broken down two main categories, namely dry waste and wet waste. Dry waste includes cattle and pig manure and poultry litter whilst wet waste comprises of cattle, pig and poultry slurry, sewage and sewage sludge. Sewage sludge is a by-product from the treatment of sewage. For energy conversion purposes, the quality of animal and human waste is important for biogas production. Biogas is a mixture of methane and carbon dioxide. The freshness and the percentage of dry solid matter content increases the biogas yield (Warburton, 1997). Wet or liquid wastes contain a low percentage of solid matter. After treating the waste, by reducing the water content and drying the material, the solid content will increase. Slurries and sewage may be subject to some dilution to improve the handling of the waste before being used for energy conversion purposes (Warburton, 1997). The dry matter content for cattle and pig slurry is 12% and 9%, respectively, for every tonne of fresh waste (Warburton, 1997). The dry matter content per tonne of poultry litter is 30%, whilst the dry matter content of manure can reach up to 60% or more (Warburton, 1997). By adding straw to cattle slurry, the dry matter content can be raised from 6% to around 12% (Baldwin, 1993a).

At present, there are no markets for animal or human waste, except for using animal wastes as farm fertilisers (ETSU, 1999). As large quantities of dry and wet animal and human wastes are generated on a regular basis, the disposal of this waste is a problem. Energy conversion could offer an alternative way to re-use and dispose of the waste. To minimise the cost of any potential projects, close proximity to the biomass source will reduce transportation and waste handling costs.

9.3.3 Agricultural Residues

Straw is the main dry agricultural residue that can be utilised for energy conversion purposes. Straw is available from cereal and other crops, such as oilseed rape, which are traditionally grown for food purposes (ETSU, 1999). Straw is produced when crops are harvested and can be recovered and baled for use (ETSU, 1999). When harvested dry, straw has a moisture content of 15% and a calorific value of 15 GJ/tonne (ETSU, 1999). Further drying reduces the moisture content and can raise the calorific value to 18 GJ/tonne (ETSU, 1999). Straw is a bulky material in proportion to its energy content. When compared with coal, the volume of straw is approximately 10-20 times greater per unit volume of energy equivalent material (Nikolaisen, 1992). By baling straw, the bulky nature of the material is reduced and the straw is easier to handle.

A market has already established for straw. Around half of the straw currently produced is used for agricultural purposes, mainly as animal bedding (ETSU, 1999). The remaining surplus straw could be utilised for energy purposes although the extent of this may vary from region to region. It has been suggested that regions which have a net surplus of straw less than 200,000 tonnes per year, large-scale energy production would not be viable (ETSU, 1999). Straw is being used on a small-scale in the UK for heating farm buildings. The economics of using straw as a fuel are affected by the price of the straw, the proximity of the straw to the energy plant, and the load factor of the plant and capital investment costs. Future research and development has been directed towards improving the cost-effectiveness of straw projects, especially in the preparation and handling of the fuel and reducing costs.

9.3.4 Forestry and Arboriculture Residues

Wood residues from forestry and arboriculture practices, such as tops, branches, foliage, logs and fallen trees can be used for energy conversion purposes. Present woodland management practices, including harvesting or thinning operations, generate wood residues. Wood can also be collected from existing woodland and forest areas. The feasibility of using wood residues for energy conversion projects depends on the availability of the biomass within a defined or reasonable catchment area, the energy content of the wood and the market for energy (Warburton, 1998). Wood can be collected, dried and used as a local fuel. The bulky nature of wood and the high water content makes localised use of the fuel more economical. Transporting wood residues to wider markets would increase the costs of projects due to increased transportation distances. Reducing the wood to chip decreases the bulky nature of wood, making it easier to transport. Wood has a calorific value of around 19 GJ/dry tonne. When harvested, the moisture content of wood can be quite high at around 55%. This lowers the calorific value to 10 GJ/tonne (ETSU, 1999). A number of on-site constraints can influence the harvesting of wood from managed sites including the nature of the terrain, soil type, weather conditions, water courses, the proximity of roadside facilities and wildlife habitats (Warburton, 1998).

Whilst wood residues from some forestry and arboriculture practices are being used for small-scale energy conversion purposes, the supply of wood has not been fully developed in the UK. Using wood has the potential to stimulate economic development at local and regional levels whilst managing wooded areas and displacing on-site brought-in energy (Warburton, 1998). To enhance the viability of projects, research needs to be directed towards the economic collection and processing of wood fuel, in particular innovative chipping and baling equipment to reduce labour and transport costs (EUROPA, 2001a).

9.3.5 Organic Municipal and Industrial Waste

Organic municipal and industrial waste is generated by domestic, commercial and industrial activities. It covers a diverse range of organic wastes including food waste, gardening waste, waste wood and packaging waste. Current waste disposal streams can contain a mixture of organic and non-organic materials. However, wastes can be separated using different waste disposal techniques, such as segregating the waste at source. Developments have taken place to separate and turn paper and plastic products into pellets. This 'refuse-derived' fuel can then be used to power energy plants. The main processes for recovering energy from waste are to burn, or incinerate, the waste regardless of its organic content. The waste disposal technique of placing waste in landfill sites produces conditions in which the waste materials are broken down and methane and other trace gases are released. In essence, this 'biogas' can be recovered and used for heat and power generation purposes.

Due to the diverse range of municipal and industrial wastes, there is a wide variation in the dry energy content of the waste materials. It has been estimated that the energy content of municipal solid wastes is around 9 GJ/tonne although this varies depending on the type of waste (ETSU, 1999). In the UK, around 100 million tonnes of waste are generated each year by households, commerce and industry (DTI, 2004a). Although the majority of this waste goes to landfill, 35% of industrial and commercial waste and 12% of household waste is recycled or composted (DTI, 2004a). Alternative ways to dispose of municipal and industrial wastes are being sought due to government policy and legislation changes, pressures to minimise and recycle waste, and shortages in landfill capacities (ETSU, 1999). Due to pressures on landfill sites and the introduction of the landfill tax, the incineration of waste or the use of waste treatment technologies, such as anaerobic digestion and pyrolysis, have become favoured waste disposal options.

9.4 Biomass Preparation

Before energy is extracted from biomass energy resources, the materials must be prepared to maximise the efficiency of the conversion process. Most biomass must be dried to enhance the calorific value of the material. Drying can take place before or after arrival at the energy plant. For the fuel supply to be continuous, biomass must be stored on site or within a reasonable distance from the plant. The volume of some energy crops and agricultural, forestry and arboriculture residues can be reduced by compressing the biomass or converting the material into chips, pellets or briquettes using specially designed machinery. Biomass resources must be screened to discard large contaminants, such as bricks or stones, which can cause significant damage to processing and conversion machinery. The quality of the biomass entering the energy plant can be guaranteed by introducing specifications to regulate the size, moisture content and calorific value of the fuel before combustion.

9.5 Conversion Technology

9.5.1 Direct Combustion

The main biomass conversion technology is direct combustion. Biomass is burnt in stoves or furnaces to provide heat that can be used directly or via boilers to produce steam for heat and/or electricity generation (Jackson and Löfstedt, 1998). Direct combustion technology is fully commercialised and mature (WEC, 1994). One advantage of direct combustion is that a wide range of biomass energy resources can be used in this technology. With research and development directed towards increasing the efficiency of the process whilst reducing capital costs, direct combustion has the potential to emerge as a flexible energy conversion option. Further research is required to demonstrate the flexibility of direct combustion, develop higher performance turbines for electricity generation, and simplify the conversion process to reduce capital costs for small-scale developments, reduce labour costs and improve wood drying techniques to increase the efficiency of the burning process (EUROPA, 2001a).

9.5.2 Carbonisation

Carbonisation converts wood into charcoal. Wood is heated to 280°C where the process becomes exothermic and the air/oxygen supply is cut off (WEC, 1994). Charcoal is produced which has double the energy density of the original material (Shaw, 1999). Carbonisation has been used for many years and is a fully commercialised energy conversion technology. The future role and development of this technology has yet to be determined (WEC, 1994).

9.5.3 Gasification

Gasification is an advanced conversion technology which has been used commercially since 1830 (WEC, 1994). A solid fuel is reacted with hot steam and air or oxygen to produce a gaseous fuel consisting of carbon monoxide, carbon dioxide, hydrogen, methane and small traces of other gases (Shaw, 1999 and Bridgwater and Evans, 1993). For electrical power generation, gasification units are available in many sizes ranging from 100 kW_e to 30 MW_e (ETSU, 1994).

Although gasification technology is fully developed and offers the possibility of using high-efficiency power conversion cycles, the economics are poor (Jackson and Löfstedt, 1998). There has been extensive research and development in using gasification for motive power applications (WEC, 1994). Extensive demonstration projects have taken place in developing countries such as Brazil (WEC, 1994). Using advanced gas turbine techniques, full scale demonstrations are required combined with a programme of demonstration to the power industry and export markets (EUROPA, 2001a). Work is also directed at reducing costs associated with using this technology.

9.5.4 Pyrolysis and Fast Pyrolysis

With pyrolysis, solid biomass is heated to high temperatures in the absence of air to produce a gas mixture, oil and charcoal (IEA, 1997). The proportion of these elements depends upon the conditions under which the pyrolysis takes place (Jackson and Löfstedt, 1998). Fast pyrolysis rapidly heats biomass to high temperatures in the absence of oxygen to produce a liquid called bio-oil, which can be used directly for fuel applications or as a source for producing chemicals (Bridgwater et al, 1999). For fast pyrolysis to work efficiently, the biomass needs to be finely ground (Bridgwater et al, 1999).

Pyrolysis and fast pyrolysis are both new technologies which are still at the demonstration stage. Research and development has been directed towards developing, piloting and optimising these technologies. Work has been directed towards finding the best conversion process for fast pyrolysis (Bridgwater et al, 1999). Research has also been undertaken on chemical production from fast pyrolysis and the development of commercial opportunities in this area (Bridgwater et al, 1999). Future research and development is being directed towards encouraging the competitiveness of the technologies, increasing the experience in using pyrolysis and fast pyrolysis whilst improving the economics for small and large-scale developments (Bridgwater et al, 1999).

9.5.5 Anaerobic Digestion

Anaerobic digestion uses bacteria to break down organic matter into biogas, fibre and liquor (Warburton, 1997). The fibre and the liquor contain low levels of plant nutrients, in particular nitrogen, phosphate and potash compounds (Warburton, 1997). The fibre is a bulky material which can be composted before being added to soil. The liquor can be used directly as a liquid fertiliser (Warburton, 1997). Anaerobic digestion is a reliable and effective way of producing biogas from organic waste (WEC, 1994). Anaerobic digestion can be used for small farm production or on a larger scale. The technology is well developed with a wide range of equipment being commercially available. Further research and development is required to disseminate information and experience with using the technology. Research and development has been directed towards improving the gas yield, optimising the solid content of feedstock and reducing capital costs (EUROPA, 2001a). The capital investment costs of anaerobic digestion projects are high. The equipment is produced to high standards to minimise any chance of corrosion (Warburton, 1997). This gives the equipment a long life span which can offset costs in the longer term. Other costs for anaerobic digestion projects include project development costs, running costs and training costs (Warburton, 1997). Efforts have been made to reduce the running costs of anaerobic projects by optimising plant reliability (EUROPA, 2001a).

9.5.6 Fermentation and Esterification

Using micro-organisms, usually yeast, fermentable sugars from wheat and sugarbeet are converted into an alcohol named 'ethanol' (WEC, 1994). The fermentation of ethanol produces large amounts of carbon dioxide which can be recovered, compressed and used in the food and beverage industries or used for refrigeration purposes (WEC, 1994). Ethanol fermentation from starches and sugars is fully developed (DTI, 2004b). Research has been directed towards developing the use of the fuel as an alternative to petrol. In Sweden, on-going trails have used ethanol to power inner city buses (SSEU, 1993). Further research and development has been directed towards identifying cheaper biomass resources and using alternative fermentable organisms, such as bacteria (WEC, 1994).

In addition to ethanol, oilseed rape and recycled vegetable oil can be used to produce biodiesel. Biodiesel is a substitute for diesel in vehicles. Oils are refined before treated with methanol to produce biodiesel. This process is called esterification. Esterificiation removes the fat from oil so that the biodiesel does not clog up the vehicles engines. Glycerine is the waste produced from this process. The main use of glycerine is for soap making. Research and development has focused on improving the technical viability and costs of biodiesel production in the UK. In particular, work has been directed towards looking at the energy and carbon balances of biodiesel and wider social and environmental costs and benefits (DTI, 2004b; Elsayed et al, 2003 and Mortimer et al, 2003).

9.5.7 Composting

Composting is an aerobic biological process in which micro-organisms decompose organic materials into a stable organic residue (Baldwin, 1993b). Composting has been used for many centuries and is a natural form of recycling (Anon, 2001a). The process depends upon the nature of the organic materials and the decomposer organisms involved (Anon, 2001a). There have been some advances in utilising the heat generated by composting for space and water heating applications. However, the future role and use of composting as an energy conversion technology is unclear.

9.6 Processing Technology

Following energy conversion, the initial outputs can either be used directly for various applications or can undergo further processing to produce electricity or refined fuels. The processing technology used can comprise either of a combined heat and power (CHP) unit, boilers, engines, turbines or refinery equipment. The type of final energy output required influences the nature of the processing technology used. In particular, there are different boiler designs depending on the moisture content, calorific value and potential contamination of the fuel. Boiler, engine and turbine technology and refinery equipment are fully mature and have been developed in line with advances in fossil fuel technology. CHP units are commercially developed. Different combustion technologies are commercially available for CHP units including grate fired boilers and fluidised bed boilers. Both grate fired boilers and fluidised bed boilers are well proven technologies with established markets. Further work is needed to reduce the capital costs of the boilers whilst improving combustion efficiencies. Advances have been made in developing smaller boilers with acceptable capital costs, which has made this technology ready for demonstration (EUROPA, 2001a).

9.7 Types of Output and Application

The biomass energy resource and conversion technology used determine the quality and type of the output. As illustrated by Figure 9.1, outputs consist of solid, liquid or gaseous products and heat and electricity which can be graded at various qualities i.e. low or high grade fuel. Initial outputs from the conversion process include heat, charcoal, gas, oil, fuel and compost. Following conversion, the energy sources can be used directly, can undergo further processing to refine the output or be used to generate electricity. As such, there are a wide range of possible applications for biomass energy, and the by-products from the conversion processes, as illustrated in the following examples:

- District heating/cooling - Although more common in Europe, biomass technology can provide heating and cooling to buildings. In the UK, a small number of energy from waste schemes are operational, providing district heating for communities in Mansfield, Nottingham and Sheffield (Open University, 1994),

- Space and water heating - Biomass energy can provide space and water heating for single or multiple rooms depending on the scale of the scheme,

- Process heating - Traditionally charcoal has been used to provide heat for smelting activities,

- Cooking - Charcoal, gas and electricity from biomass resources can be used for cooking purposes on barbecues and domestic and industrial appliances,

- Electrical applications - The electricity generated can be used to power any electrical application or can be fed directly into the National Grid,

- Motive power applications - By distilling ethanol, refining rapemethylester or using rapeseed oil, liquid biofuels can be produced to power vehicles. In particular, distilled ethanol can be used as a petrol additive or blended with diesel for fuel purposes,

- Liquid fuel applications - Liquid fuels can be used for a wide range of applications including lubrication,

- Chemical applications - Chemicals derived from biomass can be used in a range of applications including lacquers, paints, medicine, disinfectants and windscreen washer fluids, and

- Applications to improve the quality of soil - Compost can be applied to soil to improve the nutritional quality of the soil. In addition, by-products, such as fibre and liquor from anaerobic digestion, can also be used as compost or liquid fertilisers.

9.8 Economic Issues

Biomass projects face high capital investment costs due to a range of factors including the availability of the biomass, the scale of the development and the generating capacity of the plant. In particular, the transportation costs are an important factor in the economic feasibility of biomass projects. The bulky nature of the biomass, the low energy content per unit volume and the proximity of the biomass to the energy plant, can significantly affect the transportation costs of a project. As such, many biomass projects are site-specific to minimise costs. Additional costs incurred can include operational and maintenance costs, training, insurance, monitoring and costs of grid connection. Research, development and demonstration projects using biomass energy resources and conversion technologies are directed towards optimising the use of materials and the technology whilst seeking to reduce costs in the longer term.

As examined earlier in Section 8.6, the Renewables Obligation combined with the Climate Change Levy has helped to create a favourable market for renewable energy in the UK. In order to help create and maintain a biomass energy market, the Renewables Obligation has been modified to allow the co-firing of biomass with fossil fuels in existing generators until 2016 (DTI, 2004b). A phased approach has been introduced which specifically sets out to expand the use of energy crops for electricity generation purposes in the UK. Until the 31st March 2009, any amount of biomass can be co-fired with no minimum percentage of energy crops. From 1st April 2009 to 31st March 2010, 25% of co-fired biomass must be from energy crops. From 1st April 2010 to 31st March 2011, the percentage of energy crops must amount to 50% of co-fired biomass. From 1st April 2011 to 31st March 2016, this figure must have increased to 75%. From 1st April 2016, co-firing with fossil fuels will cease to be eligible under the Renewables Obligation (DTI, 2004b).

9.9 Meeting Stakeholder Expectations

9.9.1 Biomass and Stakeholders

As identified in Figure 9.1, there are a diverse range of biomass energy sources, different ways of preparing biomass, different conversion and processing technologies and different outputs and applications. Subsequently, there is also a wide range of potential biomass energy stakeholders in the UK. The complexity of this situation is problematic when seeking to evaluate biomass energy against the expectations of stakeholders. However, by looking at available local biomass energy resources and potential energy applications, local stakeholders can be identified. Within the district boundary of Sheffield, the available biomass resource comprises of agricultural by-products such as straw and waste wood from forestry practices (Grant et al, 1994c). If this boundary was extended to include the adjacent local authority districts of Barnsley, Chesterfield, Derbyshire Dales, the High Peak, North East Derbyshire and Rotherham, a larger biomass energy resource could be utilised (Grant et al, 1994c). By utilising the biomass potential of the surrounding region, agricultural land could also be utilised to grow energy crops such as SRC.

It is likely that waste wood and SRC would be reduced to wood chip at source as wood chip is easier to handle, transport, dry and cool (Shaw, 1999). Within Sheffield's built environment, it is likely that straw and wood chip would be utilised mainly for heating and cooling purposes. At present, a large percentage of energy consumed by buildings is for space and water heating applications. For example, in an average domestic building, space and water heating can account for 75% of the total energy consumed by the building (DEFRA, 2002). The majority of space and water heating in buildings in Sheffield is produced on a building-by-building basis using imported natural gas and/or electricity supplies. Space and water heating technologies, such as gas-fired and electric fires, radiators and air conditioning units, are used to convert natural gas and electricity into heating and cooling. As Sheffield is one of the few places in the UK with a district heating system in operation, there are two key types of energy consumer that can be identified, namely the district heating supplier and the end user. In relation to the energy or heat supplier, straw and wood chip could be co-fired with existing fuels in the energy plant. For the end user, it is likely that wood chip will be utilised for burning in wood room heaters, stoves and/or wood-fuelled boiler systems. Although there are end users of the heat supplied by the district heating system, this assessment will focus on those users who are not connected to the district-heating network. It is this group of end users who rely on the supply of natural gas and/or electricity for heating and cooling purposes. This group of end users have different relationships with buildings depending on whether they own and/or occupy the building. This relationship is important when decisions have to be made on how the building is heated and/or cooled.

If biomass energy is to replace or substitute existing ways of heating and cooling buildings in Sheffield, it must meet the energy expectations of the heat supplier and end users. In order to see if biomass meets the expectations of heat suppliers and end users, this section has been subdivided into two parts. The first part (Section 9.9.2) evaluates biomass energy against the expectations of the heat supplier. The expectations of accessibility are examined in Section 9.9.2.1, followed by flexibility (Section 9.9.2.2), reliability (Section 9.9.2.3) and acceptability (Section 9.9.2.4). The second part (Section 9.9.3) looks at the ability of biomass energy in meeting the expectations of end users. Accessibility is firstly examined in Section 9.9.3.1, followed by ease of use (Section 9.9.3.2), flexibility (Section 9.9.3.3), convenience (Section 9.9.3.4), reliability (Section 9.9.3.5), consistency (Section 9.9.3.6) and acceptability (Section 9.9.3.7).

9.9.2 The Heat Supplier

9.9.2.1 Accessibility

A key issue facing the utilisation of biomass by district heating suppliers is the accessibility of the biomass resource and supply. Although a biomass resource exists within Sheffield and adjacent Local Authorities, there is no infrastructure in place at present to collect, dry, process and transport wood chip and agricultural by-products to the energy plant. This raises the issue of the current status of the biomass energy market in the UK. At present, there is no market for utilising waste wood or SRC for energy purposes. Forestry waste tends to be left on site to encourage biodiversity, and there is a limited UK demand and market for energy crops. In Sheffield, there is no demand for SRC. Unless farmers have confidence in the product and have a secure market for their crops, they are unlikely to invest in SRC. Although waste wood is available and SRC could be grown, the lack of supply and demand for these products means that they are not accessible at present. In contrast, straw is accessible and is currently utilised for a variety of purposes including storing vegetables, bedding for animals and in the production of packaging (Christin et al, 1996). However, in order for straw to be utilised as a fuel, the demand for energy would have to compete with existing demands for straw.

9.9.2.2 Flexibility

For the district-heating supplier, fuels can only be flexible if the supply of heat meets demand. Unlike some other renewable energy resources, biomass is available at any time of the day and night. As it can be stored at or near the point of consumption, straw and wood chip offer a varying heat supply that can be utilised to match heat demand within the district heating network (Christin et al, 1996).

9.9.2.3 Reliability

The supply of biomass needs to be reliable, both now and in the future. Although biomass is a renewable energy source, which can be constantly replenished as it is consumed, heat suppliers need to be confident that there will be a continuous and reliable supply of fuel. As noted in Section 9.9.2.2, there is no infrastructure in place at present within Sheffield to grow, process, dry, collect and transport biomass. The existing situation of 'no market, no biomass – no biomass, no market,' will continue to have serious implications for investments into biomass production and its utilisation within district heating networks (ETSU, 1999). This situation raises the need for contracts between the heat supplier and fuel provider to ensure a continuous and reliable supply of biomass in both the short and longer term.

9.9.2.4 Acceptability

In order for heat suppliers to invest in biomass, affordability, quality and environmental concerns are important priorities. If the necessary conditions were in place, wood chip and straw can be affordable fuels. If local resources are utilised, this reduces the transportation costs of moving the wood chip and/or straw from the point of production to the point of consumption. Transportation costs can amount to a large percentage of total costs. In addition to the affordability of biomass, heat suppliers will be concerned with the performance and quality of the fuel. The moisture content of wood chip and straw determines the efficiency of the combustion process. The lower the amount of moisture in wood chip, the greater the amount of useful heat is produced (DTI, 1994). Also, the size of the particles within the wood chip or straw directly impacts the efficiency of the combustion process, the grade of the fuel produced and the value of the fuel (Shaw, 1999). Utilising biomass resources will also help heat suppliers reduce their impact on the environment. Biomass is regarded as 'carbon neutral' as the carbon emissions absorbed during the growth of the plant or tree is released during combustion. Therefore, no additional carbon is released into the atmosphere, provided that new trees are planted to replace those that are harvested (Shaw, 1999).

9.9.3 The End User

9.9.3.1 Accessibility

There are two main questions surrounding the accessibility of biomass by end users, namely how accessible is the resource and the technology used to convert the biomass into heat? As examined earlier in Section 9.9.2.1, a potential biomass resource exists in Sheffield and the surrounding area. However, the accessibility of this resource is limited, as there is no energy market for the biomass. Unless there is a secure demand for biomass, forest rangers and farmers face high levels of financial risk if they choose to invest in biomass when the market is uncertain. In addition to growing and collecting biomass, mechanisms are also needed to chip, dry, store and distribute the biomass to consumers. For straw, the existing market and supply chains could be extended. Whilst wood chip can be purchased from garden centres as it is used on gardens and allotments, this is only available in small quantities. The accessibility of biomass raises issues concerning the need to break the spiral of 'no market, no biomass – no biomass, no market' (ETSU, 1999). In particular, contracts between suppliers and end users may be needed to secure supply and demand. Whilst a potential market and potential supply exists, problems of access to information and knowing who to contact for guidance is a key issue facing the development of biomass in Sheffield and across the UK.

Unlike the accessibility of the resource, a small market exists for wood burning stoves, which can be purchased from retailers selling fireplaces and fire surrounds. Although the technology is available and accessible, the limited accessibility of biomass resources may inhibit their purchase. Whilst wood-burning technologies can be utilised on a building-by-building basis, opportunities also exist for group or community heating. Whilst the current district heating network could be extended, small biomass plants could be built which supply a group or community of end users. As with district heating networks, the advantages of group heating include lower capital costs, lower energy, operating and maintenance costs, reliable heating and cooling and the utilisation of a renewable energy source (CHPA, 2004).

9.9.3.2 Ease of Use

There are two key issues facing the ease of use of biomass. From the end users perspective, are biomass systems easy to choose as a way of heating buildings and how easy are they to operate? As demonstrated by Section 9.9.3.1, there is a limited supply infrastructure in place at present to grow or collect biomass resources and distribute the produce to end users. In addition, there is a limited demand infrastructure in place to sell, install, maintain and operate wood burning stoves and boiler systems. This raises the need to guarantee the supply of the fuel, the performance of the fuel, the technology, its installation and operation. Encouraging end users to change to biomass for heating needs is unlikely to be easy. Unfamiliarity with biomass and wood-fired technologies may label this resource as difficult to use. This may affect the performance and operation of wood burning stoves. This raises the issue for the need for end users to learn how to use wood-burning stoves to ensure the technology performs correctly.

9.9.3.3 Flexibility

Heat from biomass can only be flexible if supply meets demand. As examined in Section 9.9.2.2, wood chip can be produced to meet heating demands at any time of the day or night. Wood chip can be easily stored which allows it to meet varying demands. However, the storage of wood chip may be an issue for end users who have limited additional storage space.

9.9.3.4 Convenience

For end users who use natural gas or electricity to provide heating in buildings, changing to biomass energy resources and appropriate technologies is unlikely to be regarded as convenient. Changing heating systems in individual buildings to open fires and wood-burning stoves may be perceived as a step back in time to having coal fires. As with coal, end users may regard buying wood chip, collecting it or having it delivered, making the fire, cleaning the stove and disposing of ash as inconvenient. As examined in Section 2.2, domestic households have moved from using coal for heating to gas-fired and electric fireplaces. Coal-effect fireplaces have replaced open fires.

End users enjoy the benefits of having a coal-like fire without the disadvantages, for example, cleaning and maintaining the fireplace. Although coal-effect fireplaces are popular, there is a gap between end users having a coal or wood-effect fireplace and changing it for a wood-burning stove. Are end users willing to become more involved in energy production, for example, by putting wood in a stove? If wood is not regarded as convenient as switching on the gas fire, how can end users be persuaded to change from gas fires to wood-fuelled stoves?

9.9.3.5 Reliability

In order for straw and wood chip to be considered as an alternative to conventional heating supplies, the energy supply and technologies need to be reliable. Although biomass is a renewable energy resource which is carbon neutral, investors need to be confident that there is a market for biomass. Additionally, end users will need to be confident that by investing in biomass technologies, there is a reliable supply of energy both now and in the future. In addition to the supply of biomass, wood-burning stoves and boilers must perform in light of end user expectations. This raises the issue for the need for guarantees to be placed on the supply and quality of biomass and wood-burning technologies.

9.9.3.6 Consistency

End users expect a consistent heat supply, both now and in the future. This suggests that any changes in heating provision must continue to provide the same benefits as conventional heating supplies. Although biomass would supply end users with a familiar energy service, the way in which the heat is generated is not consistent with conventional heating provision in individual buildings. The use of biomass, in particular wood chip, is more consistent with heat production of 100 years ago. Until the Industrial Revolution, wood was a widely available and utilised resource (Shaw, 1999). This inconsistency may act as a barrier to the wider use of biomass for heating individual buildings in Sheffield.

9.9.3.7 Acceptability

End users choose energy services based on affordability, quality and wider environmental concerns. It is difficult to quantify the costs of biomass as the consumption of energy, supply of biomass and type of technology are site specific.

However, wood chip systems tend to have higher capital costs when compared to conventional energy systems. Unlike fossil fuels, there is no guaranteed market for biomass, no contracts to match supply and demand and no economies of scale to justify investment (Mather and Chapman, 1995). Further examination of the economic issues facing wood chip utilisation in the UK is discussed elsewhere (Shaw, 1999). For householders and non-profit making community organisation, the Clear Skies scheme provides grants for room heaters or stoves with automated wood pellet feeds and wood fuelled boiler systems (ClearSkies, 2004). Additionally, the scheme provides a list of installers to help ensure good quality service and products.

As discussed in Section 9.9.2.4, the quality of biomass is important. The lower the moisture content of the fuel, the higher the amount of useful heat produced. In addition, end users will need to be re-assured that the materials used and the construction of wood-fuelled stoves, heaters and boilers are of a certain quality, and their installation is properly carried out. Additionally, with the immediate and long-term impacts of energy production on the environment becoming increasingly important, the utilisation of biomass helps reduce the consumption of fossil fuels and lowers local carbon emissions.

9.10 Additional Issues

9.10.1 Smokeless Zones

Burning wood chip and straw in smokeless zones is an important issue facing heat suppliers and end users. Through the Clean Air Act in 1956, smokeless zones came into effect (Bell, 1997). This designation means that once an area has been designated as a smokeless zone, it is an offence for the occupiers of premises to allow any smoke emissions from a chimney. This has important implications for the utilisation of biomass by the heat supplier and end user (Shaw, 1999). Wood chip is an unauthorised fuel as it emits smoke when burnt. However, there are certain appliances that are approved for use in smokeless zones. If wood chip is burnt in an approved appliance, it can be used in smokeless zones (NEA, 1995).

9.10.2 Planning Issues

There are planning issues, which affect both the production of biomass resources and their utilisation in the urban environment. In relation to growing energy crops, local or national land designations may have an impact upon their growth on certain sites. Constructing energy plants will require planning permission (ODPM, 1995). Conditions may be placed on schemes to minimise any adverse environmental impacts of the scheme. Adverse environmental impacts may include visual impacts from the size of the plant, traffic movements delivering biomass to the plant and noise generated by the operation of the plant and associated traffic movements. Existing land uses and local designations may also affect the siting of energy plants. It is hoped that the draft PPS22 on renewable energy will help to promote biomass developments within areas such as Sheffield.

9.10.3 Environmental Considerations

The growth of energy crops and the collection of organic wastes must comply with legislation and regulatory requirements of planning, environmental protection and health and safety. In addition to these issues, producing energy from local biomass resources and utilising this energy on a local basis, developments may have a number of potential local environmental impacts, as listed below:

- Transport impacts – Transporting biomass resources from the point of production to the point of consumption will generate traffic. One way of minimising the impact of transport is to utilise locally available biomass energy resources,

- Visual impacts – If energy crops such as SRC are grown locally, the crops may have a visual impact on the landscape. In a study which examined public perceptions of SRC, the study participants perceived that the growth of SRC would have a visual impact on the countryside (Sadler, 1993). Also, energy plants may have a localised visual impact on the landscape,

- Ecological impact - Local ecosystems and biodiversity may be affected by the collection of energy crops, forestry wastes and arboriculture residues,

- Noise - Increased traffic movements from the source to the energy plant can add to noise levels. Also, local noise may be generated by the operation of plant machinery such as chippers, and

- Health and safety risks - There are a number of various health and safety risks associated with the handling of biogas and other trace gases. Exposure can have serious health consequences (Warburton, 1997).

9.10.4 Resource Area for Biomass

Although the accessibility of the biomass resource has been examined in relation to heat suppliers and end users, wider issues also emerge. In particular, the utilisation of biomass potential in surrounding Local Authority districts raises issues concerning the utilisation of this resource for energy demands in Sheffield. Should the biomass resource in surrounding districts be used to meet the energy demands of Sheffield or used to meet energy demands within each respective district? If a market develops for biomass and adjacent districts to Sheffield grow SRC in response, competition for the resource may emerge between Sheffield and nearby towns and cities. This situation raises questions concerning the sustainability of energy systems within urban areas. Is it possible for towns and cities to become energy autonomous? At present, towns and cities rely upon the trade of goods and services on a local, regional and national scale. Is this situation likely to continue in relation to renewable energy supply?

9.11 Key Challenges for Biomass Energy

This examination has shown that biomass energy is a diverse resource. There are many different technologies available that are at various stages of maturity. Research and development has been focused towards improving conversion efficiencies and reducing costs. In order for biomass to be utilised for heating purposes within Sheffield, it must also meet the expectations of stakeholders. As Sheffield has a district-heating network in operation, it emerged in Section 9.9 that there are two types of energy consumer in Sheffield, namely the heat supplier and the end user who is not connected to the district-heating network. The outcome of the examination of biomass energy against the expectations of heat suppliers is provided in Table 9.1.

Table 9.1 Current Evaluation of Biomass Energy against the Existing Energy System and the Expectations of Heat Suppliers

Energy Supplier Expectations	Existing Energy System	Biomass Energy
Accessibility	••	•
Flexibility	•••	••
Reliability: Now In the future	 •• •	 • •••
Acceptability, in terms of: Affordability Quality Environment Sustainability	 •• •• • •	 •• •• •• ••

Key to symbols:
- • Does not meet expectations
- •• Expectations are partially met
- ••• Meets expectations

As summarised in Table 9.1, the main problem facing biomass is the accessibility of the resource. This has additional implications in terms of the current reliability of supply. In relation to flexibility and acceptability, biomass energy competes with non-renewable forms of heat production. In addition to the expectations of heat suppliers, biomass energy was also analysed against the expectations of end users of heat, as summarised in Table 9.2. Using the stakeholder demand criteria as a basis for the analysis, the main problems facing the utilisation of biomass by end users is the accessibility of the resource, the reliability of supply and energy conversion technologies, the lack of consistency with conventional ways of heating buildings and cost issues.

For both heat suppliers and end users, wider issues of smokeless zones, planning legislation and environmental considerations face the utilisation of biomass in Sheffield. The specific obstacles facing the production and utilisation of biomass in Sheffield are summarised in Table 9.3, which summarises and simplifies the analysis contained in Section 9.9. In Table 9.3, the obstacles are sub-divided into those that affect the heat supplier and end user. It is important to note that some issues raised in Table 9.3 overlap and will affect more than one phase of development or stakeholder. The obstacles raised in Table 9.3 will be addressed alongside other renewable energy technologies relevant to Sheffield in Chapter 13.

Table 9.2 Current Evaluation of Biomass Energy against the Existing Energy System and the Expectations of End Users

End User Expectations	Existing Energy System	Biomass Energy
Accessibility	●●●	●
Ease of Use	●●●	●●
Flexibility	●●●	●●
Convenience	●●●	●●
Reliability:		
Now	●●	●
In the future	●	●●●
Consistency	●●●	●
Acceptability, in terms of:		
Affordability	●●	●
Quality	●●	●●
Environment	●	●●●
Sustainability	●	●●●

Key to symbols:

● Does not meet expectations

●● Expectations are partially met

●●● Meets expectations

Table 9.3 Obstacles Facing the Deployment of Biomass Energy in Sheffield

Stakeholder Expectations and Additional Issues	Obstacles	Heat Supplier	End User
Accessibility	The lack of supply and demand for biomass limits the accessibility of the resource	■	■
	Existing markets for straw and wood chip	■	■
Ease of Use	Lack of infrastructure in place to guarantee the performance of the fuel, technology and its installation	■	■
	Stakeholder unfamiliarity with using biomass as a fuel	■	■
	Stakeholder unfamiliarity with biomass technologies		■
Flexibility	Storage is needed at or near the point of consumption to reduce transport costs and ensure that supply meets demand	■	■
Convenience	Wood-fired stoves and boilers require end users to become involved in energy production		■
Reliability	The supply of biomass must be reliable both now and in the future	■	■
Consistency	Utilising biomass for heating in buildings is more labour intensive than conventional heating practices		■
Acceptability	End user awareness of grant availability		■
	Need to guarantee the quality of biomass	■	■
Financial Risk	Level of financial risk facing investment into biomass by producers of biomass, heat suppliers and end users	■	■
Smokeless zones	Biomass can only be burnt in approved appliances		■
Planning Issues	Local designations may affect the growth of energy crops and the siting of new energy plants	■	■
Environmental Considerations	The move towards local generation and utilisation of biomass will mean that local communities have to manage any adverse environmental benefits associated with biomass developments.		■

Key to symbol: ■ Obstacle affects this stakeholder.

10. SMALL-SCALE HYDRO POWER

10.1 Hydro Power

The potential and kinetic energy in flowing water has been harnessed for many centuries. Water flowing from higher to lower levels has been used to drive waterwheels, producing mechanical power to grind grain or operate mill machinery. From the earliest times of electricity generation, hydro power has been used to generate electrical power (NEF Renewables, 2001b). Hydro power is the smallest available renewable energy resource in Sheffield (Chapter 4 and Appendix D). It could provide Sheffield with an estimated 90 TJ of electricity per year, which could be utilised for any electrical applications within the city. By utilising hydro power, local carbon emissions could be reduced by approximately 3,400 tC (Appendix B and D). Although hydro power is available in Sheffield, it is not currently utilised. In order to investigate why this situation exists, it is necessary to examine the technical and economic status of hydro power in the UK and evaluate its ability as an electricity source in meeting the expectations of stakeholders in Sheffield.

In order to address these issues, the chapter has been subdivided into two parts. The first part (Sections 10.2 to 10.6) reviews hydro power in the broad context of the UK. The basic aspects of hydro power are introduced in Section 10.2. The resource considerations (Section 10.3) and applications (Section 10.4) are then discussed. The technical and economic status of hydro power is explored in Sections 10.5 and 10.6, respectively. The second part of the chapter examines stakeholder expectations of energy services and highlights the differences between hydro power and conventional energy technologies in delivering stakeholders with electricity. This examination provides the basis for identifying obstacles which currently face the deployment of hydro power in Sheffield. Using the relevant stakeholder demand criteria as a basis for this analysis, hydro power is evaluated against stakeholder expectations in Section 10.7. Any additional issues facing hydro power are examined in Section 10.8. In Section 10.9, the key challenges facing hydro power are raised. This section firstly summarises how hydro power performs in relation to meeting stakeholder expectations before looking at the obstacles which influence the deployment of hydro power in Sheffield.

10.2 Basic Aspects

Hydro power schemes can be subdivided into two broad categories, namely large-scale and small-scale. In the UK, large-scale and small-scale hydro power schemes have defined installed generating capacities of greater than 5 MW and less than 5 MW respectively (ETSU, 1999). The generating capacity of hydro power schemes varies according to the volume of water available and the vertical distance the water falls, referred to as the head (ICLEI, 2001b). In the UK, large-scale hydro power schemes are used for electricity generation purposes and can have generating capacities of hundreds of megawatts (ETSU, 1999). Large-scale schemes usually involve a dam with water stored in a reservoir (ETSU, 1999). Small-scale hydro power schemes are either diversion-weir or run-of-river schemes. Diversion-weir schemes use a water intake placed above a weir or behind a low dam to abstract water from the water course. Here, the water is diverted to the turbine using a pipe (penstock) or water channel (leat). The rotation of the turbine produces mechanical power which can be transferred to a generator to produce electricity (ICLEI, 2001b). An outflow returns the water to its natural course. Low dams or weirs can be used to generate power from water courses with low heads of less than 3 metres. Run-of-river schemes use the natural flow of the river to generate power without using a dam (ICLEI, 2001b and ETSU, 1996). A turbine house contains the turbine, other power generating machinery and water monitoring systems (IEA, 1991).

Small-scale hydro power plants are designed to supply small base mechanical and electric loads, supplement peak electric loads or be connected to the national grid (IEA, 1991). For supplying small mechanical loads, small-scale hydro power plants provide a continuous, reliable energy source. To meet peak electric loads, storage is required. Electrical power can be stored in batteries or pumped storage facilities, supplied directly to the source or directly onto the national grid. Batteries can provide a simple economic option for remote areas where demand is low and storage volume is limited (Anon, 2000c). Pumped storage facilities use excess electricity generated by the hydro power plant to pump water up to a holding pond. When the electricity is required, the water is allowed to flow down from the holding pond to power a standby power station (IEA, 1991). The electricity generated on site can be transmitted to local users or supplied directly onto the national grid.

10.3 Resource Considerations

The exploitation of small-scale hydro power resources is site specific. The nature of the topography, geology and hydrology of the rainfall catchment area influences the resource available, the design of the hydro power plant and the economic viability of the scheme (Laughton, 1990 and IEA, 1991). In the UK, the availability of water resources suitable for small-scale hydro power purposes varies. Good sites with hydro power potential have been exploited leaving few accessible and commercially viable sites available (ETSU, 1999). At remaining sites, planning constraints may limit the development of the resource in sensitive areas, for example, local nature reserves (DTI, 2001f). Opportunities may exist to re-develop previously exploited hydro power resources, for example, from the Industrial Revolution, through the renovation of existing works.

10.4 Applications

Small-scale hydro power schemes provide a reliable, long term energy supply. With favourable geographical conditions, small-scale hydro power schemes can generate mechanical and electrical power on a range of water courses including streams, rivers and canals (Grant et al, 1994c). In the UK, small-scale hydro power schemes are used to meet the mechanical loads of farms and the electrical loads of local buildings, with surplus electricity being exported to the national grid. In remote areas, they can be used to displace diesel-fired generators and meet some of the electricity needs of buildings not connected to the national grid (IEA, 1991). In urban areas with an industrial heritage, derelict or disused weirs, mill ponds or leats could be renovated and re-used. Sensitive engineering works and the use of local materials can integrate small-scale hydro power schemes into the local environment. Multipurpose projects can incorporate hydro power developments to help deliver local improvements including flood protection, cooling water for thermal plants, improved navigation, recreation areas and land irrigation (Jackson and Löfstedt, 1998). They can also be used as a tourist attraction and for educational purposes.

10.5 Technical Status

Small-scale hydro power technology is commercially mature and widely available. The lifespan of small-scale hydro power plants ranges from 15-50 years with the civil engineering works lasting for more than 100 years (IEA, 2000 and ETSU, 1996).

Although this technology is well-established, there is a drive to improve the existing technology, reduce the high capital costs of small-scale hydro power schemes and encourage the wider dissemination of information on developing schemes (ETSU, 1999 and EUROPA, 2001). There are many different turbines available on the market suited to differing site conditions. The most common turbine technology available are Pelton turbines for use at high head sites with low flow rates and Kaplan turbines for lower heads with higher flow rates (ETSU, 1999). Cross-flow turbines are used for run-of-river schemes (ETSU, 1999). Modern turbines have high conversion efficiencies between 85-95% (IEA, 2000). This is considerably higher than solar power technology, which has conversion efficiencies ranging from 6-30%. Research and development is directed towards improving the performance of the turbines for low head applications. A number of advances have been made in increasing the efficiency and cost-effectiveness of turbines by developing new designs and using different materials (IEA, 1997). Variable turbines for generating power at sites with low heads and/or run-of-river schemes with seasonal water flows are being developed (ETSU, 1999). Further research is needed in developing low head turbines with low manufacturing costs, improving the design of power equipment and control systems, optimising generation, addressing the environmental sensitivity of civil works and minimising the ecological impact of schemes (EUROPA, 2001).

10.6 Economic Status

The capital investment costs of constructing small-scale hydro power schemes vary depending on a range of factors including site availability, site characteristics (head and flow), the proximity of the site to the load and the degree of civil engineering works required on the site (IEA, 1991). As such, the capital costs are very site specific. If there is an existing pond or weir, costs for low head schemes may start from £4,000 per kW installed up to 10kW. If there is no existing civil works, hydro schemes are more expensive as more work is required. For medium heads, there is often a fixed cost of around £10,000 with additional costs of £2,500 per kW up to 10kW installed. As such, a 5 kW scheme could cost between £20-25,000 (EST, 2003). Operation and maintenance costs form a low percentage of the capital costs and can include insurance, annual site surveys, local rates and administration costs (ETSU, 1996). However, operation and maintenance costs can be higher for schemes with existing works as the equipment may require more maintenance than new equipment. Although hydro power technology is mature and well-established, further improvements in harnessing small-scale potential will help to reduce capital costs.

In addition to capital costs, the economics of hydro power is influenced by a range of factors including the water flow, the performance of the turbine, the capital outlay, the running costs and current electricity prices. Both the Climate Change Levy, introduced in 2001, and the Renewables Obligations, introduced in 2002, has helped to create a favourable market for renewable energy developments, including the exploitation of hydro power resources. As examined in Section 8.6, the Climate Change Levy has placed an energy tax on electricity and natural gas consumed by the business and industrial sector. By switching to electricity generated from renewable energy sources, business and industrial energy users can claim exemption from the scheme. In addition to targeting the end users of electricity, licensed electricity suppliers must purchase a specified amount of their electricity from renewable energy sources under the Renewables Obligations scheme. Electricity suppliers must prove compliance with the scheme by producing certificates or make a buy-out payment or both (Ofgem, 2004b). This intervention by the Government and Ofgem has helped to stimulate the renewable energy market in the UK and this, in turn, may help to stimulate the utilisation of small-scale hydro power sites.

10.7 Meeting Stakeholder Expectations

10.7.1 Small-scale Hydro Power and Stakeholders

Within Sheffield, small-scale hydro power plants are more likely to be grid connected as not all potential sties are adjacent to or very near to identified points of consumption. However, there is also the possibility of stand alone systems, which would need additional storage. If sites are grid connected, feeding electricity directly onto the national grid will avoid electricity storage costs. In this situation, the main stakeholders of electricity from small-scale hydro power sites in Sheffield are likely to be licensed electricity suppliers rather than end users of electricity such as domestic users. In order for small-scale hydro power to meet the energy expectations of electricity suppliers, the electricity supply must be accessible, flexible, reliable and acceptable, as set out in Section 8.7.1. This examination is necessary in order to identify any obstacles which will affect the wider deployment of small-scale hydro power in Sheffield. The ability of hydro power to meet these expectations is examined below.

10.7.2 Accessibility

The main question which electricity suppliers are likely to ask of hydro power in Sheffield is are the sites accessible? Although hydro power is not currently exploited in Sheffield, the MIRE renewable energy study identified 12 potential hydro power sites, as illustrated by Figure 10.1. At each of these sites, it was assumed that a 200 kW hydro turbine could be installed (Grant et al, 1994c). As Figure 10.1 shows, these potential sites are located to the west of the city on the River Loxley and the River Don. Surrounding land uses comprise of domestic buildings, business and industrial works or wooded areas. Most of the sites are former hydro schemes which now form part of the industrial heritage of Sheffield. It is possible that the derelict weirs, disused leats and mill ponds could be adapted and renovated for use in new hydro power schemes. This could significantly reduce initial investment costs and the subsequent unit cost of electricity generation. Due to potential conflicts with existing land use and the problem of flooding, the MIRE study suggested diversion weir schemes as opposed to schemes with dams as practical development of the latter would be severely constrained (Grant et al, 1994c).

10.7.3 Flexibility

Hydro power is available at any time of the day or night and its utilisation can provide a continuous source of electricity. To increase the flexibility of hydro power, electricity storage and a back-up supply of electricity are needed. As examined in Section 10.2, electricity can be stored in batteries, in pumped storage facilities or shipped to supply demand using the national grid. Whilst battery storage can be expensive and pumped storage requires a suitable location to be identified and developed, the national grid is a more familiar way of managing the wider balances of supply and demand. This system acts as a 'virtual' storage and, although the electricity is used to meet demand elsewhere, electricity can be taken from the grid in exchange for electricity generated by hydro power in Sheffield.

10.7.4 Reliability

If electricity suppliers are to invest in hydro power, both the energy supply and technology must be reliable. Hydro power is free, carbon neutral energy source and its utilisation would provide a continuous, reliable supply of electricity. Electricity suppliers and other potential investors would need to be confident that hydro power sites will

Figure 10.1 Potential Hydro Power Sites in Sheffield

provide a given amount of electricity over a particular period. If electricity suppliers are to invest in hydro power in Sheffield, they also need to be reassured that the technology performs well and delivers what it sets out to deliver. This raises the need for guarantees to be placed on the materials used, the manufacture, the installation and the operation of hydro power technologies.

10.7.5 Acceptability

Investing in small-scale hydro power developments will help electricity suppliers meet their Renewables Obligations. As examined in Section 10.6, electricity suppliers must purchase a set amount of electricity from renewable energy sources as set out under the Renewables Obligations (Ofgem, 2004b). In order for potential hydro power sites in Sheffield to quality under the Renewables Obligations, they must be certified under the scheme. If electricity generated by hydro power in Sheffield is going to be bought by electricity suppliers, it must be of a specified quality. The electricity must meet frequency and fluctuations specifications and other technical regulations as specified by the electricity utility in accordance with transmissions and distribution codes (Terence O'Rourke plc, 1998).

10.8 Additional Issues

10.8.1 Planning Issues

Most small-scale hydro power developments will require planning permission with the possible exception of refurbishing existing schemes where there is no change of land use (ODPM, 1995). Conditions may be placed on planning permission to minimise any adverse environmental impacts of the schemes, for example to minimise the visual intrusion of the powerhouse building (ETSU, 1996). Existing land uses and national or local designations such as National Parks may restrict small-scale hydro power developments. In relation to renewable energy developments, the planning system is often quoted as one of the key barriers facing the success of developments (DTI, 2003). Although in the past guidance in this area has been limited, the new draft PPS 22 may provide more guidance, support and advice for developers and Local Authorities.

10.8.2 Legal Issues

The impounding and abstraction of water is regulated by the Environment Agency under The Water Resources Act 1991. For small-scale hydro power schemes with dams or weirs, an impounding licence will be required. This licence will determine the level and location of the dam or weir and ensure an adequate supply of water downstream (ETSU, 1996). An abstraction licence is required where the flow of water will be diverted from the main water course to the turbine (ETSU, 1996). The ownership of land at existing weir sites or new hydro power sites can pose problems for any hydro power development. Determining the ownership of land on which the hydro power plant is to be built and adjacent land that may be affected by the development, for example for access purposes, can involve consulting multiple owners (ETSU, 1996). Water courses can form property boundaries. Also the ownership of banks and existing structures can be complex (ETSU, 1996). Securing land for hydro power developments either by purchasing the land or through rental agreements at a reasonable price pose a serious issue for hydro power developments (ETSU, 1994). Leasing arrangements may be required for buildings, pipelines, leats and grid connection cables (ETSU, 1996). Land prices and rents vary according to local circumstances (DTI, 2001f).

10.8.3 Environmental Considerations

The construction and operation of small-scale hydro power schemes can have localised impacts on the environment. The construction of such schemes can take between 1-2 years (ETSU, 1999). During this period, the building of temporary dams or other features can disturb the river bed and river ecology (DTI, 2001f). Once constructed, hydro power schemes can operate for a long period of time. During their lifetime, there will be some local environmental considerations which must be addressed. Common issues of concern, which could occur in Sheffield, are outlined below:

- Visual impact - The physical presence of the dam, water intake, powerhouse or access roads can be visually intrusive (DTI, 2001f),

- Ecological impact - Diverting the flow of the water and/or maintaining the level of flow can have an impact on local ecology, namely fish populations. In particular, the scheme can have an impact on the passage of fish, their migratory patterns and spawning grounds. Hydro power schemes can also cause inadvertent pollution of the water course (Laughton, 1990), and

- Impact on groundwater levels - Groundwater levels may be affected by the construction of a dam or weir (DTI, 2001f).

10.9 Key Challenges for Small-scale Hydro Power

As examined above, small-scale hydro power is a reliable, long term energy source that can be used to supply small base mechanical and electric loads or supplement peak electric loads (IEA, 1991). The technology is proven, reliable and commercially available (ETSU, 1996). Despite such advantages, the feasibility of small-scale hydro power schemes depends upon geographical conditions which determine the size of the resource and the capital costs of developing the site. Further advances in turbine design may help to increase the viability of future developments. However, in order for the electricity generated by small-scale hydro power sites to be purchased by electricity suppliers, it must their expectations of electricity supply, as summarised in Table 10.1. As summarised in Table 10.1, the main problems facing hydro power is the accessibility of the resource and high capital costs. However, in terms of flexibility, reliability, quality and environmental acceptability, hydro power competes with existing electricity supplies. In some respects, hydro power is more favourable than existing supplies.

In addition to the supply-side of utilising hydro power sites, local people will have to deal with the impacts of local electricity generation. Planning, legal and environmental issues will have to be taken into consideration when developing hydro power sites within the city. These issues or obstacles are summarised in Table 10.1, which simplifies and summarises the analysis carried out in Sections 10.7 and 10.8. In Table 10.2, the obstacles are subdivided according to the expectations of electricity suppliers, the impacts on the wider community and at which stage of deployment each obstacle affects. The deployment of small-scale hydro power in Sheffield can be subdivided into two key phases; first, the proposal, and secondly, the installation and operation of the site. It is important to note that some of the obstacles raised in Table 10.2 overlap and affect more than one phase of development. The obstacles raised in Table 10.2 will be addressed alongside other renewable energy technologies relevant to Sheffield in Chapter 13.

Table 10.1 Current Evaluation of Small-scale Hydro Power against Energy Supplier Expectations and Existing Energy Systems

Energy Supplier Expectations	Existing Energy Systems	Small-scale Hydro Power
Accessibility	●●●	●●
Flexibility	●●●	●●●
Reliability:		
Now	●●	●●●
In the future	●	●●●
Acceptability, in terms of:		
Affordability	●●	●●
Quality	●●	●●●
Environment	●	●●●
Sustainability	●	●●●

Key to symbols:
- ● Does not meet expectations
- ●● Expectations are partially met
- ●●● Meets expectations

Table 10.2 Obstacles Facing the Deployment of Small-scale Hydro Power in Sheffield

Energy Supplier Expectations and Additional Issues	Obstacles	Small-scale Hydro Power	Operation & Maintenance
Accessibility	Surrounding land use and risk of flooding may constrain the development of some sites	■	■
Flexibility	Need to match supply with demand. This has storage implications.		■
Reliability	Confidence that the site will deliver a reliable electricity supply	■	
	Stakeholder confidence in materials used, the technology, its installation and operation	■	■
Acceptability	Each site must be certified under the Renewables Obligations	■	
	Electricity supply must meet frequency and fluctuation specifications as set out by the electricity supplier		■
Planning Issues	Need for local authorities to be more pro-active in encouraging and supporting hydro power developments	■	
Legal Issues	Licences required to operate.		■
	Ownership of land on which the hydro power plant is to be built needs to be determined	■	■
	Land needs to be secured either through purchase or rental. Leasing arrangements may need to be drawn up.	■	■
Local Environmental Considerations	Local communities will need to manage and mitigate against any adverse environmental impacts associated with the development including visual and ecological impacts and impact on groundwater levels.		■

Key to symbol: ■ The obstacle affects this stage of deployment.

11. EXISTING ENERGY CARRIERS

11.1 Linking Supply to Demand

The term "energy carriers" refers to a means of transporting energy from the point of production to the point of consumption. Not only does this refer to the physical infrastructure which is used to distribute energy carriers to end users, but it also refers to the medium through which the energy is carried. In the UK, natural gas and electricity are the two main energy carriers or mediums through which energy is supplied to end users. Natural gas is distributed to end users using a network of nationally interconnected pipelines, whilst electricity uses an electrical transmission and distribution network. In addition to natural gas and electricity, a few urban areas use water and steam as energy carriers to distribute heat to end users via local networks of interconnected pipelines. This system is called district heating, which can also be used to supply cool water. Hot water can also be used to drive absorption chillers to provide air conditioning within buildings connected to the network.

This chapter builds upon previous examination of electricity, natural gas networks and district heating networks and highlights additional issues facing the utilisation of these three energy carriers in the deployment of renewable energy in Sheffield, specifically, and the UK, generally. The chapter is split into three key sections which address electricity networks (Section 9.2), natural gas networks (Section 9.3) and heating and cooling networks (Section 9.4). The ability of electricity and natural gas in meeting stakeholder expectations of energy supply was examined in Chapter 2. In addition to the issues raised in this earlier chapter, the basic aspects of electricity networks are introduced in Section 9.2.1. In Section 9.2.2, additional issues of price (Section 9.2.2.1) and storage (Section 9.2.2.2) are examined. Issues facing the future development of the electricity network are summarised in Section 9.2.3. The examination of natural gas networks takes place in Section 9.3. The basic aspects are introduced in Section 9.3.1 followed by an examination of additional issues in Section 9.3.2. Additional issues facing the production and supply of gas (Section 9.3.2.1), storage (Section 9.3.2.2) and the distribution network (Section 9.3.2.3) are also raised. The future development of gas is examined in Section 9.3.3.

In addition to electricity and natural gas networks, Sheffield has a district heating network. The ability of this heating network to meet stakeholder expectations of energy supply was examined in the analysis of biomass energy in Chapter 9. In order to provide an insight into district heating networks, Section 9.4 examines the status of this energy carrier in the UK and additional issues facing its utilisation in Sheffield. The basic aspects are examined in Section 9.4.1, followed by an examination of resource considerations (Section 9.4.2), the technical status (Section 9.4.3) and the economic status of district heating networks (Section 9.4.4). Additional issues facing the utilisation of district heating networks in the deployment of renewable energy in Sheffield are also considered in Section 9.4.5. In Section 9.5, the key challenges surrounding the future role of existing energy carriers in the deployment of urban renewable energy systems are summarised.

11.2 Electricity Networks

11.2.1 Basic Aspects

Electricity is a flexible and convenient form of energy which is used for a wide range of applications ranging from powering electric appliances in the home to electric vehicles. Electricity is supplied to end users using a transmission and distribution network. Once produced, electricity is fed into the national grid system. Electricity is distributed using overhead lines supported by poles and pylons or underground cables. Using transformers, the voltage of electricity is gradually reduced for use by different applications (EA, 1999). Electricity is consumed by a large variety of energy users including most industries and the domestic and service sectors. Over the last five years, the domestic, industrial and service sectors have experienced a growth in electricity consumption and this trend is forecast to continue (DTI, 2000a, 2000b). At present, electricity is generated from a wide range of energy sources including fossil fuels, nuclear energy and renewable energy sources (DTI, 2000a). Although renewable energy use is favourable in terms of reducing carbon dioxide emissions and contributing to sustainable development, renewable energy sources only supplied 3% of UK electricity generation in 2002 (DTI, 2003a).

11.2.2 Additional Issues

11.2.2.1 Price

Until the introduction of the Renewables Obligation in 2002, the price of electricity has always been a key issue facing renewable electricity developments. The generation of electricity from fossil fuels has had significant economic advantages over renewable energy supply. This well-established industry has operated economies of scale which have produced cheap electricity. However, the full costs of production and consumption, namely the external social and environmental costs, are not reflected in the price of conventional electricity. External costs include negative impacts such as social disruption from energy production activities and environmental impacts resulting from the release of carbon emissions into the atmosphere (Shaw, 1999). Positive impacts include employment opportunities. It has been suggested that by internalising the external costs of conventional electricity production, the true cost of electricity per unit will be reflected and a level playing field between different sources of electricity will emerge.

Whilst efforts have been made to stimulate demand amongst end users for renewable electricity, for example green electricity tariffs and an energy tax placed on electricity and natural gas consumption by business and industrial end users, the introduction of the RO has created a demand for renewable electricity by electricity suppliers. As discussed in Chapter 8, licensed electricity suppliers must source a specified amount of their electricity generation from renewable energy resources. This specified amount will increase on an incremental basis up to 10.4% by 2010/11 (Ofgem, 2004a). This market intervention has helped to stimulate a market for renewable electricity. As the Renewables Obligation rises, the demand for renewable electricity will grow. As the demand for renewable electricity outstrips supply, electricity suppliers may be willing to pay a premium for renewable electricity and there will be increased investment in renewable energy to meet Renewables Obligation targets.

11.2.2.2 Storage

Electricity is produced to meet demand as the electricity network has limited capacity to store additional electricity. Short-term fluctuations in demand can be met using pumped storage and demand management techniques, for example, off-peak electricity tariffs (Open University, 1994). Large-scale fluctuations in demand are unlikely to be met by the present electricity system. It has been suggested that the intermittent nature of renewable energy generation makes it unsuitable for electricity generation. However, the present generation system predominately uses nuclear and coal, oil and gas-fired plants which operate at various technical and economic efficiencies. The technical difficulties of matching supply with demand using traditional plants have been overcome in order to provide an energy service to end users. Although some renewable energy sources are intermittent, for example, solar energy and wind power, others, like hydro power, provide reliable energy opportunities. In addition, biomass can be stored in large quantities and utilised to meet fluctuations in electricity demand.

11.2.3 Future Developments

Although electricity developments have historically been dominated by large-scale generators using fossil fuels, the liberalisation of the electricity market has opened up opportunities for smaller generators using alternative energy sources. It is likely that the growing demand for electricity combined with environmental concerns will stimulate demand for new generating capacity and the supply of green electricity. Although some favourable conditions are in place, namely the opportunity to compete in the energy market and the utilisation of the existing national grid infrastructure, high investments costs and premium prices for green electricity currently impede development. Further initiatives are required to stimulate end user demand for green electricity whilst making prices more competitive.

11.3 Natural Gas

11.3.1 Basic Aspects

Natural gas is consumed on a large-scale within the UK for many diverse applications ranging from heating buildings to powering vehicles. Town gas, a mixture of carbon monoxide and hydrogen, was commonly used in the UK from the mid-nineteenth century until the early 1970s. The discovery of large natural gas reserves in the North Sea in the 1960s stimulated investment in the conversion to natural gas between 1967 and1973 (Roberts et al, 1991). During the oil crises of the 1970s, natural gas emerged as a convenient and cheap energy source and, as a result, the use of natural gas has rapidly risen over the past thirty years (DTI, 2000a). In 1999, the domestic sector consumed the largest amount of natural gas in the UK (DTI, 2000a). Natural gas is distributed to customers using a national network of pipelines. The majority of natural gas comes from gas reserves in the North Sea. Once ashore, the gas is cleaned and compressed before being distributed to gas users. For safety reasons, the gas is monitored to ensure that the pressure is maintained.

Natural gas is a fossil fuel resource with a finite lifespan. The future use and economics of natural gas relies on the discovery and accessibility of gas reserves. It has been suggested that biogas, produced from anaerobic digestion treatment of animal and human waste, could be used as an alternative to natural gas. Biogas is a mixture of methane and carbon dioxide. As with other biomass resources, the carbon dioxide absorbed during the growth of the biomass is released upon combustion, making the gas carbon neutral (Shaw, 2001). Although biogas is commonly used in some countries, for example China, the use of biogas in the UK has been limited to a few research, development and demonstration projects. In China, biogas is used daily for many applications including cooking, lighting, electricity generation, powering machinery and for use as a fuel in internal combustion engines (Hill et al, 1995). The use of biogas on a large-scale within the UK raises a number of issues regarding its distribution, integration with natural gas, or use as a replacement for natural gas in the future.

11.3.2 Additional Issues

11.3.2.1 Production and Supply

The main issue facing the use of biogas for gas applications in the UK is the lack of a production and supply infrastructure. At the moment, there is no demand for biogas and, as a result, there is no need to co-ordinate the production and supply of biogas. Within the UK, the raw materials are available for biogas production. It is likely that small-scale biogas developments will face high capital investment costs due to the low demand for the product and lack of economies of scale (Shaw, 2001). As such, the large-scale production of biogas would enhance the economic viability of such schemes. However, this situation is unlikely to occur until a market develops.

11.3.2.2 Storage

Unlike electricity, gas can be stored in pressurised containers, underground caverns or in former gas reservoirs (Anon, 2001c). Storing gas in pressurised containers allows gas to be transported and used for stationary and/or mobile applications. Large-scale storage of gas in underground caverns or former gas reservoirs allows gas to meet any surges in demand.

11.3.2.3 Distribution Network

Although the existing gas infrastructure in the UK is based upon natural gas, any gas of the same quality as natural gas can be used. This has important implications for the supply and use of biogas in the UK. Biogas has a lower methane content than natural gas and, as a result, has a lower calorific value of 20 MJ/m^3 when compared to 31.9 MJ/m^3 for natural gas (CADDET, 2001). Biogas would require refining and upgrading to the same quality as natural gas before it could be used in the existing gas infrastructure. Projects in the Netherlands have proven the technical and economic feasibility of producing and upgrading biogas for use within the existing gas grid and domestic properties (CADDET, 2001). Without refining, new distribution pipelines and equipment would be required, adding to the costs of biogas developments.

In the longer term, it may be necessary for biogas to replace natural gas. Upgraded biogas can be mixed with natural gas or used as a replacement for natural gas (Stöhr, 2001). Mixing upgraded biogas with natural gas may help in the transition from natural gas to biogas. Additionally, the use of biogas in the existing gas infrastructure would help facilitate the distribution of biogas on a large-scale. Biogas developments in the UK tend to operate on a small-scale for local consumption. The supply of biogas to end users using the existing gas infrastructure is a convenient way of introducing biogas and renewable energy to existing gas users. This has significant advantages as end users are not directly involved in the production of biogas (Christin et al, 1996).

11.3.3 Future Developments

Biogas has significant potential as a viable energy source in the UK. As illustrated here and in an previous working paper (Shaw, 2001), the technology is available, projects can be economically feasible, the existing gas infrastructure can be utilised, and, perhaps more importantly, there is a constant and growing demand for gas across all sectors in the UK. Although this demand for gas exists, the discovery of large natural gas reserves has reduced the need to find alternative gas sources. However, the growing dependency upon natural gas may have important implications for the utilisation of biogas in the near future. The strategic issues of access to reserves when existing reserves decline or become scarce may initiate biogas developments in the UK in the near future.

11.4 District Heating and Cooling Networks

11.4.1 Basic Aspects

Buildings provide protection from outside weather conditions and temperatures. In order to create comfortable living conditions within buildings, space heating or cooling may be necessary. In the UK, buildings are commonly heated by oil or gas-fired boilers or electricity. Heating equipment, such as radiators or blow heaters, are used to distribute the heat. For buildings requiring cooling, individual or centralised air conditioning units are used. Heating equipment and air conditioning units usually supply individual applications. The supply of heat or cool air to a number of buildings connected to a central plant is uncommon in the UK. Heating and cooling networks can operate on a group, community or district level. Although there are no precise definitions, the term used tends to indicate the scale of the heating network. Group heating involves a group of a few buildings, community heating supplies more buildings on a "community level", and district heating distributed heat to a wider area such as a town or city. Heating networks can supply buildings with space and water heating or heat for industrial applications. In addition, heating networks can be used to supply cool air to buildings. This combined usage allows the system to be utilised throughout the year and replaces the need for individual boilers and air conditioning units.

Heating networks use water as an energy carrier although some systems use high pressure steam (Christin et al., 1996). There are two main types of heating network available, namely open and closed loop heating systems. Open systems use a single pipeline to supply buildings with hot tap water. Closed systems supply hot water to the customer and return the cooler water to the plant using a looped pipeline. Heat exchangers are used to transfer the heat from the pipeline into the building (Anon, 1999b). Closed systems heat water to higher temperatures than open systems as the water is not directly used as hot tap water. Variations in seasonal temperatures affect the demand for heating and cooling in buildings. To ensure that the supply of heat or cool air meets demand, the system must be capable of supplying peak loads. Single or multiple boilers can provide backup storage for any shortfalls in supply. Large-scale storage facilities including steel water tanks, gravel/water storage pits or chemical storage may be used (Löttner et al., 2000). Careful management is required to ensure that the heating and cooling loads are met and that temperatures remain constant.

11.4.2 Resource Considerations

Heating and cooling can be produced from a single fuel or a range of fuels including fossil fuels, municipal waste, waste heat from industrial processes, biomass, solar power and geothermal heat. Geothermal heat occurs naturally in ground water aquifers or hot dry rocks (ETSU, 1999). The utilisation of renewable energy sources in heating and cooling networks has a number of advantages over the use of fossil fuels and non-organic municipal waste. Renewable energy sources are sustainable as they are "naturally replenished as they are consumed" (IEE, 1994). Little or no additional carbon dioxide emissions are released into the atmosphere following the utilisation of renewable energy sources such as solar power or biomass. In addition to the environmental benefits, the utilisation of renewable energy in heating and cooling networks has a number of economic and social advantages. As illustrated elsewhere, individual, small-scale renewable energy schemes face high capital investment costs (Shaw, 2001). The development of a number of renewable energy schemes within an area, improves the economic feasibility of the projects. Renewable heating and cooling networks are a convenient way of supplying energy to end users whilst utilising renewable energy sources. End users have access to renewable energy sources whilst not being directly involved in the technical and non-technical aspects of renewable energy systems (Christin et al., 1996). In addition, the requirement for individual boilers and coolers is replaced using the heating network, with any operational or maintenance of the network being the responsibility of an external body. As a result, the end user receives heating and cooling when it is required without being directly involved in the operation of the heating system (Christin et al., 1996).

11.4.3 District Heating and Cooling Networks in the UK

In the UK, approximately 1% of the total housing stock is connected to community heating networks (CHPA, 1998). There is no available information on the use of heating networks for community cooling applications in the UK, although this is likely to be low. District heating networks were first introduced in the early 1900s as a form of low cost heating. However, the systems were largely oil-fired and were installed in council housing. A combination of the oil crises in the 1970s and a decline in the construction of council housing estates led to a decline in the installation of heating networks. Some systems installed during the 1970s are still in operation today with new schemes being introduced in urban areas, for example:

- Community Heating System, Nottingham - This system has operated since the 1970s and supplies reliable, low cost heat and electricity to residents, businesses and institutions in Nottingham. The system uses municipal waste to generate heat and electricity,

- Onyx Environmental (Sheffield) Ltd - An energy from waste scheme provides cooling, heating and electricity to a range of end users on the city's green heat network. This scheme has been in operation since 1988 (Onyx, 2004),

- Community Heating System, London Borough of Tower Hamlets - A CHP plant is used to generate heat and electricity for use by domestic housing, a school and a leisure centre, and

- Southampton City Council - District heating, cooling and electrical power is distribution to a number of buildings in the city (Anon, 2000a). This system partly uses geothermal energy sources.

The majority of heating networks within the UK are powered by fossil fuels, although a small percentage use municipal waste sources (CHPA, 1998). In other countries, including Germany, Austria, Sweden and Denmark, renewable energy sources are used in district heating networks. In particular, biomass heating systems, solar-assisted heating systems or combined solar and biomass heating systems, are in operation. For heating networks utilising solar power, the network provides convenient energy storage. In such instances, the heat collected during the daytime is stored in the heating system. The hot water or space heating can be utilised during the evening and night when there is no solar power available directly. The utilisation of a range of fuels enhances the security of energy supply, allowing the heating and cooling network to function effectively during times of high fuel prices or scarcity. The utilisation of renewable energy sources can avoid issues surrounding fuel scarcity. In addition, the networks can combine supply from individual renewable energy sources.

11.4.4 Technical Status

District heating networks can be utilised to provide both heating and cooling purposes. In relation to heating, there are two main ways of providing the initial heat source for district networks, namely boilers and CHP plants. Both boilers and CHP plants can be fuelled by a wide range of fuels ranging from fossil fuels to biomass energy sources. The heat generated from burning fuels in the boilers is transferred to water and distributed via pipes and radiators to where the heat is required (Harland, 1998). Boilers are a mature and well established technology. Research and development is directed towards improving the efficiency of boilers. CHP or cogeneration simultaneously generates useable heat and power, usually electricity, in a single process although, trigeneration, which uses absorption coolers, can provide cooling and chilled water (Meeks, 2001). CHP plants are a more efficient means of generating electricity and heat than conventional plants. Large-scale CHP plants can be 80% efficient overall, comparing heat and electricity output to fuel input. If the plant is located on site and the energy is used on site, the energy losses from transmission and distribution are low and less fuel is required (EA, 1995). CHP plants range from micro, domestic and small-scale units operating from a few kilowatts up to 1 MW to large-scale plants operating at 1000's of MW supplying electricity to power markets (EA, 1995 and Meeks, 2001). Micro and domestic CHP units are an alternative to the domestic boiler. For such technology, research and development has been directed towards optimising heat and power loads, and developing the use of fuel cells for energy storage and electricity generation. Future developments aim to deploy the technology on a large-scale. Small-scale and large-scale CHP plants are a relatively mature technology using gas turbines and gas engines for power generation. Research and development has been directed towards improving energy efficiency, developing cooling systems using absorption chillers, developing small turbines, fuel cell technology applications and lowering costs of smaller units (Meeks, 2001).

There are two main types of cooling technology used in conjunction with district heating networks, namely centralised cold water production and individual refrigeration systems. Centralised cold water systems produce cold water in a centralised plant and distribute the water to end users using a network of insulated pipes (Christin et al., 1996). Individual refrigeration systems are connected directly to the district heating network. Each building requiring air conditioning is fitted with absorption chillers. Chillers require a cooling tower to release heat into the atmosphere (Christin et al., 1996). However, developments have taken place and systems with multiple chillers can operate using a single cooling tower. Research and development in cooling technology has been directed towards developing storage techniques, in particular cool thermal storage and thermal ice storage.

District heating and cooling is distributed to end users using a pipeline network. The distribution network can suffer heat/cooling losses depending on a number of factors including pipe insulation, the length of the pipe work, the size of distribution pipes and temperature levels (Anon, 1999b). Different systems have different controls for delivering the heat to end users. In Sweden, substations are used as an interface between the district heating system and the end users. Heat exchangers are used to transfer the heat from the district network to each building. The substations maintain the indoor temperature and hot tap water temperature at constant levels without fluctuations (Anon, 1999b).

11.4.5 Economic Issues

District heating and cooling networks cannot easily be categorised in terms of scale, energy source, technology or application. As such, the economic feasibility of developments is project specific. For example, the economic feasibility of heating and cooling networks using CHP plants varies depending upon the size of the CHP unit. At the moment, only large-scale units can compete with conventional heating methods (Meeks, 2001). Ways of making CHP more attractive as an investment is currently being explored (Meeks, 2001). Such developments are likely to have a positive impact on the economic feasibility of renewable energy projects. As illustrated elsewhere, renewable energy developments face high capital investment costs with long payback periods (Shaw, 2001). Heating and cooling networks face relatively high capital investment costs per unit of heat delivered. The operation and maintenance of the systems are influenced by the operating hours of the systems (IEA, 2001). Refurbishing existing schemes or installing heating and cooling networks into new developments may lower costs. Schemes powered by fossil fuels are likely to be currently more competitive than those utilising biomass energy resources due to the low price of fossil fuels. Limited biomass supply chains currently exist due to the lack of demand for biomass fuel (Shaw, 2001). The absence of fair competition between different resources for energy applications makes it difficult for alternative energy sources to succeed. Biomass-fired district heating has significant environmental advantages over fossil fuel heating especially when comparing the release of carbon dioxide emissions. However, the impact of fuel combustion on the environment is not reflected in energy prices. Commitments by the UK government in reducing carbon dioxide levels through the introduction of the Climate Change Levy and other instruments, such as the Landfill Tax, may help facilitate a move towards the development of district heating and the utilisation of renewable energy sources.

In the supply of heat and means of payment by end users, different heating companies have different arrangements. In Sheffield, Onyx Environmental (Sheffield) Ltd have set a connection fee, a fixed charge which includes operation and maintenance costs and a charge for the heating or cooling supplied to the end user. Most of the buildings connected in Sheffield have meters which allow end users to pay for the amount of heat consumed rather than pay a fixed rate (CHPA, 1998). The costs for connecting to district heating networks can be significant depending on the extent of the distribution network. For small-scale users, including domestic buildings, district heating can be expensive. District heating can be a viable alternative in areas where existing heating systems are old or unreliable. For large-scale applications with a large heating demand, district heating can be more economical than traditional methods. In order to compete with traditional heating methods such as boilers, district heating must be competitive and reliable. From experiences in Sweden and Denmark, district heating is a viable option for areas which have a high concentration of buildings and, as such, high heat load densities. Heat load density is the amount of heat demand per unit area. The heat load density affects the capital costs per unit of heat delivered. The location of heating plants varies according to demand. By locating the plant close to the demand, pipeline instalment costs and network distribution losses are reduced.

11.4.6 Additional Issues

11.4.6.1 Community Ownership

Presently, the majority of heating consumed within the UK is produced within individual buildings. The utilisation of renewable heating and cooling networks would replace the need for individual heating systems. In addition, the heating networks could be owned and operated as private or public ventures. In Denmark, 60% of domestic heating systems are community-owned with 40% being commercially-owned (Macpherson, 1998). As such, community ownership has acted as an effective mechanism in developing district heating networks and, in particular, the utilisation of renewable energy sources for heat production. Within the UK, community ownership of energy schemes is rare, although a few schemes exist. Cultural differences between Denmark and the UK have affected the development of community heating schemes. In countries such as Denmark and Sweden, higher fossil fuel prices, limited access to natural gas sources until the 1980s, and the high priority placed on environmental issues, have helped the use of renewable heating networks (Anon, 1999b). In the UK, low fossil fuel prices, the increasing use of natural gas and low priority placed on the way heat is produced and consumed has had an impact on the development of heating networks. One key obstacle facing clean energy technologies is the low priority placed on energy issues by end users (Brown, 2001). This low priority or value affects the utilisation of renewable energy sources and the development of renewable heating and cooling networks.

11.4.6.2 Property Ownership

In city centres, high building densities and high energy demand provides opportunities for affordable district heating and cooling networks to be developed. However, the willingness of property owners to connect to the networks may have a significant impact on the utilisation of such a scheme. In particular, buildings which have multiple owners, for example several flat owners in one building, will require the consensus of all owners before the building can be connected. Ways to encourage connection to heating networks include providing information about the scheme and metering opportunities. Metering allows the owner or occupier to pay for the amount of heating/cooling consumed rather than a flat rate. Previous experience with heating networks in the UK has shown that the payment of a flat rate has resulted in heating mis-management in buildings (Owen, 1992). In such cases, metering and/or information provision will help occupiers use heat wisely (Owen, 1992).

11.4.7 Future Developments

District heating and cooling networks have an important role to play in the utilisation of renewable energy sources and the provision of heating and cooling within buildings. District heating networks offer a flexible way of heating and cooling buildings. In particular, district heating networks can connect many different renewable energy sources in different locations. They can also provide storage for intermittent renewable energy sources. One example is the heat produced from active solar systems. If excess heat is produced, this could be stored on the district heating network until it is required by the producer of the solar heat or by other users. Similarly to the national grid, district heating networks act as a form of "virtual storage". It allows end users to receive heat without getting directly involved in operation of the system (Christin et al, 1996). For several owners of individual renewable energy systems, district heating networks provide the opportunity for group heating networks to develop. Although the technical expertise is available as district heating and cooling networks operate successfully in other countries, economic issues and cultural issues need to be overcome in order for renewable-sourced district heating and cooling networks to develop in the UK.

11.5 Key Challenges facing Existing Energy Carriers

The key issues facing the utilisation of electricity, natural gas networks and district heating and cooling networks as a means of supplying customers with renewable energy have been highlighted. The main issues facing the use of each of these energy carriers have been systematically examined and the issues facing the utilisation of the energy carriers' in future renewable energy developments have been raised. From this examination, it is clear that each energy carrier has an important role to play in the short and long-term utilisation of renewable energy sources in the urban environment. Electricity and gas are the most viable options in the short-term with the possibility of utilising district heating and cooling networks in the longer-term. It is clear that electricity and gas are popular energy carriers which meet a wide range of energy applications across all sectors. Additionally, well-established distribution infrastructures are in place and electrical and gas-fired appliances are manufactured on a large-scale. Electricity is currently generated from a wide range of fuels including fossil fuels and renewable energy sources. Once generated, electricity from any source can be fed directly into the national grid system and supplied to end users. Whilst only minor changes may be required to the national grid when new generating capacity is added, economic issues can significantly affect the feasibility of electricity projects. For renewable electricity projects in particular, grid connection charges, combined with the low price charged by electricity companies to domestic users exporting electricity to the national grid, can significantly affect the economics of small-scale developments (Shaw, 2001). For energy suppliers, there is the added challenge of managing an electricity network full of distributed electricity suppliers. As end users will also become local electricity generators, energy suppliers may become "managers" of the balance between supply and demand.

In addition to the growing demand for electricity, there is also a high demand for natural gas. Although the availability of large natural gas reserves has reduced the need to find alternative gas sources at present, the growing reliance on a popular but depleting energy source such as natural gas may stimulate biogas developments in the future. One key issue facing future biogas developments is the utilisation of the existing natural gas infrastructure. From this examination, it is clear that biogas can be upgraded and used in the existing natural gas network. If, in order to satisfy future gas demands, biogas is identified as a viable way forward, natural gas and biogas can be mixed together and distributed to end users using the existing natural gas infrastructure. This is likely to make any transition towards the wider use of biogas within the UK easier than developing new infrastructures.

Space heating and cooling are important factors in creating comfortable internal conditions within buildings. Heating and cooling, regardless of source, can either be generated for individual applications or distributed to multiple users using an interconnected network of pipes. Although district heating systems are commonplace in countries such as Denmark or Sweden, few such systems operate within the UK. Although the technical expertise exists to operate such networks, other issues prevent their utilisation. Feasibility studies are required to assess the economics of such developments and cultural changes must take place in order to facilitate any move towards the wider utilisation of district heating and cooling networks in the UK. Opportunities exist for community involvement in district heating networks and the utilisation of renewable energy sources for energy production. Although community ownership of local schemes is not widely practised and renewable energy sources are not widely used, such schemes present an opportunity to localise energy generation and consumption whilst empowering local communities.

12. HYDROGEN

12.1 A New Energy Carrier

With growing pressures to reduce carbon dioxide and other greenhouse gas emissions and move towards sustainable energy production, hydrogen has been hailed as "the fuel of the future" (Hart, 2001). Hydrogen is a light element with a high-energy content making it suitable for use as an energy carrier and a form of energy storage for stationary and transport applications. Despite its versatility, hydrogen is not widely utilised as an energy carrier at present. If, in the pursuit of a sustainable urban energy system based on renewable energy, hydrogen has a role to play, it is necessary to establish the current status of hydrogen developments in the UK and its potential applications, its performance against stakeholder expectations of energy supply and any wider non-technical and non-economic considerations facing its production and utilisation within a city such as Sheffield, specifically, and the UK, generally.

In order to address these issues, the chapter has been subdivided into two parts. The first part (Sections 12.2 to 12.7) reviews hydrogen in the broad context of the UK. The basic aspects of hydrogen are introduced in Section 12.2 followed by an examination of the resource considerations in Section 12.3. The technical status of the technology used to produce hydrogen (Section 12.4), storage and transportation options (Section 12.5) and fuel cells (Section 12.6) are then systematically examined. Economic issues are discussed in Section 12.7. The second part of the chapter examines the use of hydrogen against existing stakeholder expectations of energy services. This examination provides the basis for the identification of any obstacles which are likely to face the use of hydrogen in buildings in Sheffield. Using the stakeholder demand criteria, as outlined in Chapter 2, hydrogen is evaluated against the expectations of stakeholders in Section 12.8. Additional issues facing hydrogen are examined in Section 12.9. In Section 12.10, the key challenges facing the production and utilisation of hydrogen are discussed. This section firstly summaries how hydrogen performs in relation to meeting stakeholder expectations before looking at the specific obstacles which may influence the deployment of hydrogen in Sheffield.

12.2 Basic Aspects

Hydrogen is a naturally occurring and abundant element which is found in combination with other elements, such as oxygen in water and carbon in fossil fuels and biomass energy sources. Hydrogen has a high energy content which has made it suitable for use as a chemical resource and an energy carrier where weight is a key issue, for example, fuel for spacecraft (Zittel and Wurster, 2001). Hydrogen has a long history of use in the UK. In the early twentieth century, hydrogen was mixed with carbon monoxide for use in town gas supplies. With the discovery of natural gas reserves, town gas was replaced by natural gas and the demand for hydrogen fell. Although hydrogen ceased to be used on a daily basis for energy demands in buildings, it continued to be produced for industrial applications. Hydrogen still continues to be produced on a large-scale by the industrial sector. It is also used to produce fertilisers, hydrated fats in the food industry and for rocket fuel in space programmes. Although changes in the energy sector have reduced the demand for hydrogen, increased environmental and sustainability concerns associated with energy production and its utilisation may stimulate a growth in the demand for hydrogen. In order for hydrogen to meet energy needs whilst reducing the impact of its production and use on the environment, hydrogen must be produced from renewable energy sources as opposed to fossil fuels. As such, the source of hydrogen is vital in terms of the environmental implications of energy production. Producing 'renewable hydrogen' will help to avoid greenhouse gas emissions released during the combustion of fossil fuels, in particular, carbon emissions. Although renewable hydrogen may have an important role to play, current research is investigating possible links between hydrogen and climate change (Anon, 2003 and Choi, 2003). If the demand for renewable hydrogen increases, further research will be needed in this area.

12.3 Resource Considerations

Ideally, the production of hydrogen must use sustainable energy resources and have a minimum impact on the environment. Current hydrogen production uses fossil fuels, although water resources and biomass resources offer plentiful sources of hydrogen, as summarised below.

- Fossil fuels - As noted in Section 12.2, the production of hydrogen from fossil fuels results in resource depletion and the release of carbon dioxide and other harmful emissions. This makes fossil fuels an unsustainable source for future hydrogen production, although mixing hydrogen with natural gas may have an important role during the transition phase from the use of natural gas to the wider use of hydrogen,

- Water is a readily available renewable resource which contains hydrogen and oxygen. By using electrolysis, hydrogen can be produced from water. It is foreseeable that water will have an important role to play in the future production of hydrogen, and

- Biomass – Any biomass energy sources, for example, land and aquatic plants and organic wastes contain hydrogen (Shaw, 2001). The combustion of biomass is carbon neutral as the carbon dioxide released on combustion is absorbed during the growth of replacement plants. As such, the direct production of hydrogen from biomass is important particularly in relation to reducing the impact of hydrogen production on the environment and offering a sustainable option for producing hydrogen in the longer term.

12.4 Production Technology

12.4.1 Existing and New Processes

There are a number of ways of extracting hydrogen from solid, gaseous or liquid resources. Gasification and pyrolysis techniques can be utilised to produce hydrogen from solid fuels such as coal or wood resources. Steam reforming is a well-established process used to extract hydrogen from natural gas. In the production of hydrogen from water, electrolysis can be used. New processes in photoelectrolysis and photobiology are being developed.

12.4.2 Gasification

Gasification can be used to extract hydrogen from any solid fuel including biomass energy resources. Here, the solid fuel is reacted with hot steam and air or oxygen to produce a gaseous fuel consisting mainly of carbon monoxide, carbon dioxide, hydrogen and methane (Shaw, 1999 and Bridgwater and Evans, 1993). Gasification technology is mature and has been used commercially since 1830 (WEC, 1994). Despite this maturity, the economics of the gasification process are poor (Jackson and Löfstedt, 1998). Research and development has been directed towards reducing the costs of the technology.

12.4.3 Pyrolysis

Pyrolysis is a relatively new technology, which has been directed at converting the energy in biomass into useful forms of energy. Using pyrolysis, solid biomass is heated to high temperatures in the absence of air to produce a mixture of gases, including hydrogen, oil and charcoal (IEA, 1997). Research and development have been focused on optimising the efficiency of the conversion process, increasing the competitiveness of the technology and improving the economics of small and large scale developments (Bridgwater et al, 1999).

12.4.4 Steam Reforming

Steam reforming is a two-stage process commonly used for producing hydrogen from natural gas. Firstly, steam is used to heat the natural gas to high temperatures to produce a gaseous mixture of hydrogen, carbon monoxide and carbon dioxide. By applying more steam, more hydrogen is produced. Steam reforming can produce hydrogen yields of 70-90% (US DOE, 2001a). Steam reforming of natural gas is a mature technical process which can be utilised on a large scale.

12.4.5 Electrolysis

Electrolysis is a technique in which an electric current is passed through water, separating the hydrogen and oxygen molecules. Water electrolysis is a well-established technique that has been used commercially. Research and development have been directed towards developing high-pressure water electrolysis and high temperature water electrolysis whilst reducing production costs (Zittel and Wurster, 1996). Advances have taken place in the utilisation of hydrogen in renewable energy projects. Whilst water is a renewable energy source, the source of the electricity used for electrolysis is an issue. Electricity generated from fossil fuels utilises a finite resource and its production releases carbon dioxide emissions. The utilisation of electricity generated from renewable energy sources has the advantage of being carbon neutral.

12.4.6 New Processes

There are new processes being developed to extract hydrogen from compounds whilst minimising the impact of the process on the environment. One such technique involves the use of photosynthesis for hydrogen production. During photosynthesis, green plants convert solar energy into chemical bonds involving carbon and hydrogen (Shaw, 2001). Research and development have been directed towards using the photosynthetic activity of bacteria and green algae to produce hydrogen (US DOE, 2001b). Additionally, photoelectrolysis is a technique under development, in which a semiconductor is immersed in water and sunlight is used to produce hydrogen and oxygen (US DOE, 2001a).

12.5 Storage and Transportation Options

12.5.1 Existing and New Options

In order to fully utilise hydrogen for heat, electricity and transport applications, stationary and mobile storage options will be required. There are two main storage options currently available for hydrogen purposes that are used in the storage of natural gas and nitrogen, namely compression and liquefaction. In addition, advances are taking place in the use of metal hydrides, carbon microfibres and glass spheres for the storage and transportation of hydrogen.

12.5.2 Compressed Gas

Compressing hydrogen allows more gas to be stored in a given volume and distributed for subsequent use. This storage option is a well-established technique currently used for compressing natural gas, although hydrogen compressors are also available. The technology used for compressing, storing and distributing natural gas can be modified and used for hydrogen applications (Zittel and Wurster, 1996). Gas can be stored above or below ground. Currently, large-scale storage of gas is in large aquifers or caverns with small-scale storage using tanks (Zittel and Wurster, 1996). Research and development in the storage and transportation of gas have been directed towards optimising technical efficiencies whilst reducing the costs of small-scale production. Specific work has focused on developing compact mobile pressurised gas tanks for use in gas-powered vehicles (Zittel and Wurster, 1996).

12.5.3 Liquefaction

Liquefaction is a technique whereby materials assume a liquid-like state. This technique can be used to produce liquid nitrogen, helium and hydrogen. Liquefaction plants currently exist with capacities ranging from 200 kilgrammes per day for research purposes to 60 tonnes per day for industrial purposes (Zittel and Wurster, 1996). Liquid hydrogen can be stored in containers or tanks for stationary or mobile applications. The storage of liquid hydrogen has been developed through space applications where the requirements are to store large quantities for long periods (Zittel and Wurster, 1996). Insulation is required due to the low temperatures of the liquid hydrogen. As such, the storage costs of liquid hydrogen are high. Cost reduction has been the main focus of research and development programmes. Research has investigated the use of alternative insulation materials, the energy efficiency of conversion and other production methods (Zittel and Wurster, 1996). In addition, work has been directed towards a liquid hydrogen infrastructure. In Germany, for example, a fuelling station for liquid hydrogen vehicles is in operation at Munich Airport (Pehr et al, 2001).

12.5.4 New Storage Options

Research and development is being directed towards finding new ways of storing hydrogen. One option is the use of metal hydrides. This involves reacting hydrogen chemically with a metal (US DOE, 2001b). By heating the metal later, hydrogen is released. It is hoped that the development of this technique will allow large amount of hydrogen to be stored in small volumes. Further research has been directed towards increasing the storage capacities of metal hydrides, reducing costs and using metal hydrides for mobile applications (Zittel and Wurster, 1996). For mobile applications in particular, technical advances in rechargeable batteries have led to the application of using hydrogen-absorbing alloys in metal hydride batteries (Geng et al, 1998).

Research and development is taking place in using absorption storage techniques for hydrogen. By using carbon micro fibres, large volumes of hydrogen can be absorbed and stored (Anon, 1999b). Advances in this area are taking place in Germany, Japan and Canada. In particular, research and development has been directed towards improving production methods and storage capacities (Anon, 1999b). Developments are taking place in high-pressure storage options. Glass spheres allow high-pressure storage of hydrogen. The permeability of glass allows the spheres to be filled with hydrogen. By applying heat, the hydrogen is released from the spheres for later use (US DOE, 2001b).

12.6 Infrastructure and Appliances

12.6.1 Hydrogen Infrastructure

If the demand for hydrogen increases in the UK, it has been proposed that there will be a transition period in which hydrogen will be gradually introduced as an energy carrier. In order for hydrogen to be supplied to end users, ways of introducing and supplying consumers with hydrogen are being investigated. One advantage of hydrogen, as noted in the use of hydrogen in town gas, is that is can be mixed with other fuels. During this transition period, hydrogen could be mixed natural gas and supplied directly to end users using natural gas networks. Current research in the use of hydrogen in natural gas networks is being investigated. If hydrogen cannot be used in existing gas networks, separate hydrogen networks will need to be developed. The future role and application of hydrogen has been the focus of numerous studies and research programmes. Hydrogen programmes have been established in many countries including Japan, Iceland, Germany, USA and across the EU. Developments range from the introduction of hydrogen vehicles and hydrogen fuelling stations to the establishment of hydrogen economies. Iceland, in particular, plans to become the world's first hydrogen economy by 2040 (Worldwatch, 2001).

12.6.2 New Appliances

In addition to the need for a supply infrastructure, new technologies will need to be developed to utilise hydrogen for different applications across all sectors. Within buildings in particular, new appliances which operate on hydrogen or a hydrogen/natural gas mix will be needed. Whilst these appliances will continue to meet consumers existing needs, for example gas-fired cookers and gas-fired heating systems, they will operate using the new energy carrier. Whilst research into developing new domestic and non-domestic appliances which operate on hydrogen is limited at present, significant research is taking place in developing hydrogen powered fuel cells for mobile and stationary applications.

12.6.3 Fuel Cells

A fuel cell can be defined as "an electrochemical device that continuously changes the chemical energy of a fuel (hydrogen) and oxidant (oxygen) directly to give electrical energy and heat, without combustion" (Anon, 2004b). Hydrogen can be used in a fuel cell to generate electricity. Any 'waste' heat produced from the generation of electricity can be used for space and water heating and/or cooling purposes. Within a fuel cell, the energy generated from a chemical reaction between a fuel, such as hydrogen, and oxygen or air, can be directly converted into electrical energy or used for heating applications (ETSU, 1999 and Smith, 1999). Fuel cells operate in a similar manner to batteries with no moving parts and are quiet when in use (Smith, 1999). However, fuel cells differ in many respects to batteries. With fuel cells, the fuel is stored outside the cell and the cells do not run down or require charging (US DOE, 2001b). Electricity and heat will continue to be produced as long as the fuel is supplied (Renzi and Crawford, 2000). A wide range of fuels can power fuel cells, including natural gas and hydrogen. The conversion of any fossil fuel releases waste products, in particular carbon emissions. In order to minimise the impact of fuel cells on air quality and the environment, "renewable hydrogen", produced from renewable energy resources, could be used as an alternative to fossil fuels. By combining pure hydrogen with oxygen or air, the only waste product will be water. Fuel cells running on hydrogen produced from biomass will have zero direct carbon dioxide emissions (Brandon and Hart, 1999).

Although there are many different types of fuel cell available depending upon the application, fuel cells can be divided into two main groups - low temperature and high temperature fuel cells. Low temperature fuel cells operate at less than 100°C and start quickly (Hart, 2001). Low temperature fuel cells can have low or high power densities. Low power densities are suitable for small, stationary applications. High power densities are ideal for transport applications. High temperature fuel cells operate at between 600-1000°C. These cells take a long time to warm up, making them unsuitable for mobile applications (Hart, 2001). High temperature fuel cells are also suitable for stationary domestic and non-domestic applications on a small and large scale. The cells can generate useful waste heat which can be used for space and water heating and cooling purposes. In addition, temperatures of 500°C or more can be produced. This heat could be utilised by industrial applications and/or used to generate additional electrical power (Brandon and Hart, 1999).

Although fuel cell use is not widespread, there are a growing number of mobile and stationary applications. In particular, fuel cell powered buses are in operation in Munich, Vancouver and Chicago, and Ford Motor Company and Daimler Chrysler are developing private cars powered by fuel cells. There are different fuel cells available that are at different stages of maturity and commercial availability. For all fuel cells, research and development has been directed towards improving cell performance, reliability and life expectancy, reducing manufacturing costs, achieving high efficiencies and simplifying the cells (EUROPA, 2001b). It is envisaged that fuel cells will have many applications in the future, particularly at a domestic level. Research and development is taking place in developing residential fuel cells which are the size of domestic washing machines (Smith, 1999). To assist in the integration of fuel cells into domestic and non-domestic energy generation, public acceptance of fuel cells is paramount. The introduction of new technology is dependent upon being accepted by users (LBST, 2001). As such, there is a need to further demonstrate the application of fuel cells on a domestic and non-domestic level to help any future transition (EUROPA, 2001b).

12.7 Economic Issues

The main economic issues facing the use of hydrogen are the high capital investment costs associated with the production of hydrogen and fuel cells, and the establishment of a supporting infrastructure. The source of the hydrogen and the production method used affects the cost of the hydrogen. The production of hydrogen from renewable energy sources may be viable for sites where fossil fuels or grid connection is expensive or unfeasible (Dutton et al, 2000). The utilisation of fuel cells in energy conversion faces high capital, operation and maintenance costs when compared with other technologies (Brandon and Hart, 1999). Technological advances are directed towards reducing costs. However, fuel cell prices would benefit from economies of scale where increased production will reduce unit costs (Renzi and Crawford, 2000). Fuel cell plants are currently being constructed in Germany and the USA (Hart, 2001). It has been predicted that a range of different markets with different prices will emerge for fuel cells as a result of the diverse number of potential applications of fuel cells (Brandon and Hart, 1999). The widespread utilisation of hydrogen will require a supply and distribution infrastructure. Research and development has been directed towards investigating ways in which a hydrogen infrastructure can be introduced quickly and with minimum costs (Dunn, 2001).

12.8 Meeting Stakeholder Expectations

12.8.1 Hydrogen and Stakeholders

As examined above, there are many technical and economic issues facing the utilisation of renewable hydrogen as an energy carrier in urban areas. However, in the future, renewable hydrogen could have an important role in linking renewable energy supply to end users. As such, it must be able to meet the expectations of stakeholders. As the utilisation of renewable hydrogen in Sheffield is likely to affect both energy suppliers and end users, this section has been subdivided into two parts. The first part (Section 12.8.2) evaluates renewable hydrogen against the expectations of energy suppliers. The second part (Section 12.8.3) looks at the ability of renewable hydrogen to meet the expectations of end users.

12.8.2 The Energy Supplier

12.8.2.1 Accessibility

A key issue facing the utilisation of renewable hydrogen by energy suppliers is the accessibility of the resource and/or the supply of hydrogen. If renewable hydrogen is produced from biomass energy resources, this will have implications on the use of biomass within Sheffield. Ideally, renewable hydrogen should be produced from surplus biomass resources. If not, there may be conflicts over the use of biomass resources in Sheffield, for example, will biomass resources be used for heat production primarily or will they be used to produce renewable hydrogen? If biomass is going to be the main resource for hydrogen production, this raises issues concerning the accessibility of local biomass supplies. As examined previously, some biomass resources are available although largely inaccessible. The lack of infrastructure in place to collect, dry, process, store and transport biomass is a key problem which has implications for the production of renewable hydrogen from biomass supplies. An alternative resource available to energy suppliers is water. Using electrolysis, hydrogen can be produced from water supplies. This can only be considered as renewable, however, if the electricity used comes from renewable energy sources. If there are conflicts over the use of biomass energy resources, water resources may offer an alternative way of producing renewable hydrogen.

In addition to problems regarding the supply of hydrogen In Sheffield, there is no demand for renewable hydrogen as an energy carrier. As with some renewable energy technologies, a situation of "no market – no supply, no supply – no market" exists. Unless energy suppliers have confidence in hydrogen and the infrastructure is in place to produce hydrogen and distribute it to end users, they are unlikely to invest in hydrogen technology.

12.8.2.2 Flexibility

Renewable hydrogen can only be considered as flexible if the supply of energy meets demand. If hydrogen is produced from local biomass resources, biomass can be stored at or near the point of production and/or consumption. Similarly to natural gas and electricity supplies, water is supplied to buildings via underground pipelines. As both of these resources can be stored or easily accessed, they offer a variable energy supply that could be used to match demand.

12.8.2.3 Reliability

In order for hydrogen to be considered as a new energy carrier in Sheffield, the supply of renewable hydrogen must be reliable over the longer term. If biomass energy and water resources are to be utilised in the production of hydrogen, this has implications on the reliability of the supply of these resources. Whilst both biomass and water are renewable energy resources which are carbon neutral, the inaccessibility of the existing biomass resource in Sheffield has implications on the supply of biomass for hydrogen production. Energy suppliers will need to be confident in the supply of hydrogen, hydrogen technologies and the support infrastructure. In order to develop confidence, guarantees could be introduced to ensure that the energy carrier and associated technologies perform according to expectations.

12.8.2.4 Acceptability

In order for energy suppliers to invest in renewable hydrogen, energy suppliers must be confident that it is affordable, of sufficient quality and can satisfy environmental concerns. At present, there are high capital costs facing hydrogen as there is no demand for this energy carrier. As there is no demand, energy suppliers are unlikely to invest in renewable hydrogen until it has been tried and tested on a larger scale than at present. As blending hydrogen with natural gas is still being researched, it will be a long time before the quality of hydrogen is determined. Utilising biomass resources will help energy suppliers reduce their impact on the environment.

12.8.3 The End User

12.8.3.1 Accessibility

There are two main questions facing the accessibility of renewable hydrogen by end users, namely how accessible is hydrogen and how accessible are hydrogen technologies? For the energy supplier and end user, hydrogen is not accessible at the moment nor is the supporting infrastructure. Although fuel cells have been trialled in the UK, for example, the use of fuel cells in black taxi cabs in London, their wider application is limited at present (Mourato et al, 2004). This has implications on the utilisation of hydrogen and fuel cells by end users within buildings in Sheffield. In particular, questions are raised regarding the short, medium and long term application of hydrogen and fuel cells. At what point will fuel cells powered by renewable hydrogen become available to end users for utilisation within buildings? What role will hydrogen have in the deployment of renewable energy in a city such as Sheffield?

12.8.3.2 Ease of Use

There are two main issues surrounding the ease of use of hydrogen. From the end users perspective, is hydrogen easy and safe to use and are fuel cells easy to operate? Unlike existing energy carriers of natural gas, electricity and district heating in Sheffield, end users are unfamiliar with the production and utilisation of hydrogen for energy purposes. This unfamiliarity may cause end users to perceive hydrogen, and fuel cells, as difficult, and perhaps dangerous, to use. Without careful management and safety procedures, all fuels are dangerous. Like other fuels, hydrogen can burn. Although hydrogen can catch on fire in air at a range of concentrations, it disperses rapidly and the fire burns out quickly. The flames released during combustion are nearly invisible and radiate with almost no heat. In sectors where hydrogen is used, for example the space or chemical industry, expertise and safety procedures exist (Pehr et al, 2001). As such, the large-scale use of hydrogen would require standard safety levels to be introduced. However, most end users are acquainted with safety standards in relation to the operation of electrical equipment and machinery. As such, having safety procedures for the use of hydrogen may not be a problem.

As fuel cells are still being developed and tested, it is difficult to determine the ease of use of this technology by the end user. Renewable hydrogen, hydrogen technologies and the supporting infrastructure are all unavailable within urban areas at present. As such, there are no mechanisms in place in which end users can buy renewable hydrogen, purchase or trial fuel cells or other domestic and non-domestic appliances that operate on hydrogen. Also, there are few trained specialists whom end users can contact for advice and information on the use of hydrogen within buildings. Once hydrogen and fuel cell technologies become available, end users will need to learn how to use the new technologies to ensure they perform correctly.

12.8.3.3 Flexibility

For the end user, hydrogen can only be considered as flexible if the supply of energy meets demand. As such, hydrogen-powered appliances will need to be sized to match the demands of the end user. In addition, end users are likely to ask if fuel cells switch off and whether they are immediate to respond to the flick of a switch. As end users are unlikely to become involved in the technical side of hydrogen and hydrogen-powered appliances, the appliances must be able to operate remotely within buildings and end users must be able to operate them successfully and safely. If hydrogen is not perceived to be flexible, it is unlikely that end users will use hydrogen.

12.8.3.4 Convenience

It is debatable whether end users would see any transition towards the wider use of renewable hydrogen as convenient. If hydrogen is supplied directly to buildings and existing appliances can be converted to operate on hydrogen, it may be regarded as convenient. However, if end users are required to purchase fuel cells and other hydrogen-powered technologies, this may be regarded as inconvenient. In order to increase the convenience of hydrogen, fuel cells could be marketed within showrooms alongside existing technologies and positive marketing strategies could be used. In many ways, the transition towards the wider uses of hydrogen parallels the conversion from town gas to natural gas. Although natural gas offered a cheaper and less dangerous energy supply, people perceived it to be dangerous, particularly as there was no smell associated with natural gas. Adding a smell and developing "modern" appliances which operated on natural gas, promoted the widespread use of natural gas as an energy carrier. It may be possible that similar methods are deployed to assist the wider utilisation of hydrogen in buildings in Sheffield.

12.8.3.5 Reliability

End users are likely to question the reliability of hydrogen against the perceived reliability of other energy carriers, especially natural gas. As examined earlier, the supply of hydrogen will depend upon the availability of biomass energy, and possibly, water resources. For end users who invest in hydrogen technologies, there is likely to be a need to develop guarantees to reassure the end user that the energy carrier and the technologies perform correctly and are reliable over the guarantee period.

12.8.3.6 Consistency

End users expect a consistent supply of energy, both now and in the future. This suggests that any changes in energy provision must continue to provide end users with the same benefits as conventional energy carriers. If hydrogen is supplied directly to buildings, as with other energy carriers, the use of hydrogen will be consistent with existing ways of receiving energy carriers. If fuel cells are used, end users may become more involved in energy production in buildings. This inconsistency may act as an obstacle to the use of renewable hydrogen in urban areas.

12.8.3.7 Acceptability

End users choose energy services based on affordability, quality of supply and wider environmental and sustainability considerations. As hydrogen is a new energy carrier, it is difficult to quantify cost of hydrogen and fuel cells. Additionally, there are no grants available to assist investment by end users into hydrogen-powered technology. In addition to cost, the quality of supply is an important consideration of end users. If energy suppliers provide hydrogen for use in buildings, end users are likely to expect a quality service from energy suppliers and hydrogen of a certain quality. These expectations of quality service and energy supply stem from existing expectations which consumers place on electricity and gas providers in the UK.

In addition to cost and quality issues, some end users are also concerned about the impact of energy production and utilisation on the environment. The utilisation of hydrogen, produced from water and biomass resources, will have many benefits. It will assist in the deployment of renewable energy to end users in Sheffield, local carbon emissions will be reduced and the utilisation of renewable hydrogen would contribute to the long term sustainability of energy production and supply in Sheffield.

12.9 Additional Issues

12.9.1 Public Acceptance of Hydrogen

One issue that will have to be overcome in the pursuit of a hydrogen economy is the public acceptance of hydrogen. The introduction of a new fuel, technology and infrastructure is largely dependent on the acceptance by its users. From research undertaken elsewhere on risk assessment, the perception of risk has been found to be different to that of actual risk. In the case of hydrogen, the development of a hydrogen economy will require users to interact with hydrogen and its infrastructure on a daily basis. Such research has examined the acceptance of hydrogen technologies, public knowledge of hydrogen and to identify areas where information is needed (LBST, 2001). The research concluded that people, who came into contact with hydrogen technologies, for example travelling on a hydrogen bus or through educational programmes, were more inclined to accept hydrogen technologies than those who knew little about hydrogen. To increase public acceptance of hydrogen, the research recommended that demonstrations and pilot projects be introduced and information and key contacts on hydrogen needs to be readily available to the public and targeted through educational campaigns (LBST, 2001).

As highlighted by a recent study, hydrogen and fuel cells must meet the 'needs' or expectations of end users. The study, which examined driver preference for fuel cell taxis, showed that drivers were concerned about crime, personal safety and the impacts of traffic congestion on the health of drivers (Mourato et al, 2004). The trailing of new, cleaner and quieter fuel cell taxis was welcomed as these vehicles replaced old, noisy and dirty taxi cabs. Although people often consider hydrogen vehicles to be dangerous, the main drawbacks were identified as limited mileage and the cost of hydrogen when compared to diesel vehicles and the lack of refuelling stations across the city (Mourato et al, 2004).

12.9.2 Transition Period

There are well established infrastructures for the distribution of electricity, natural gas and transport fuels from the source to the point of consumption. Such infrastructures allow for the effective distribution of the energy on a large-scale to a wide range of diverse applications. For the utilisation of hydrogen as an energy carrier, chemical storage or transport fuel to materialise, the necessary infrastructure must be in place to facilitate its use. In some countries, hydrogen infrastructures exist on a small-scale. In Germany, producers of hydrogen, including chlorine and chemical industries, supply hydrogen into local networks (Zittel and Wurster, 1996). However, the adoption of hydrogen infrastructures on a large scale is limited by the "chicken and egg" situation. Without demand for hydrogen, there is no need to create a supply infrastructure, although without the necessary infrastructure in place, any demand for hydrogen cannot be fulfilled. Additionally, technical improvements in fuel cells and hydrogen storage options are needed to ensure the technical and economic feasibility of using hydrogen in stationary and mobile applications (Hart, 2001).

Should the adoption of hydrogen as an energy carrier become a reality, there are many issues concerning the move towards a hydrogen economy. Although it is agreed that a hydrogen economy cannot happen overnight, there is a great deal of speculation and confusion surrounding the transition period from the present fossil fuel economy to renewable energy hydrogen based economy. In particular, it is uncertain whether natural gas networks can be used for hydrogen or whether new infrastructures will be required. This confusion places uncertainty on the use of hydrogen as an energy carrier and its wider utilisation within the existing energy system in the UK. Ways of overcoming such uncertainties may emerge from the experiences of Iceland in its transition to a hydrogen economy by 2040. Whilst any move towards a hydrogen economy will have significant costs, the economic costs need to be weighed against the environmental and social benefits of hydrogen.

12.10 Key Challenges facing Hydrogen

From this examination, it is evident hydrogen has the potential to become a valuable energy carrier, a form of chemical storage and a transport fuel Although the technical expertise is available, further research and development is required in the production, storage and transportation of hydrogen between energy suppliers and end users. Additionally, significant advances are required in the use of fuel cells for energy production and storage for mobile and stationary applications. In order for hydrogen to be utilised as an energy carrier in Sheffield, it must meet the expectations of energy suppliers, as summarised in Table 12.1. For the energy supplier, renewable hydrogen is problematic in terms of the accessibility and reliability of supply, affordability and quality. This stems from technical and economic issues facing the utilisation of hydrogen technology at present and wider obstacles facing the utilisation of renewable energy sources in Sheffield, in particular, the accessibility of biomass energy resources. From the perspective of the end user, as summarised in Table 12.2, hydrogen could be a reliable energy carrier in the future although problems surround the accessibility, ease of use, flexibility, convenience, reliability, consistency and acceptability of hydrogen at present. In the short to medium term, the production and utilisation of hydrogen in Sheffield faces a number of obstacles. The obstacles facing the production and utilisation of hydrogen and fuel cells are presented in Table 12.3. Table 12.3 provides a simplified summary of the analysis of hydrogen against existing consumer expectations in Sections 12.8 and 12.9. It is important to note that some of the issues raised in Table 12.3 overlap. However, there are many parallels between the obstacles facing renewable hydrogen and those facing renewable energy technologies. In particular, the lack of supply and demand, support infrastructure, systems to guarantee the performance of hydrogen technologies and the lack of confidence in hydrogen as an energy carrier are key obstacles facing its utilisation. The obstacles raised here will be addressed alongside the solutions facing the wider deployment of renewable energy technologies relevant to Sheffield in Chapter 13.

Table 12.1 <u>Current Evaluation of Hydrogen against the Existing Energy System and the Expectations of Energy Suppliers</u>

Energy Supplier Expectations	Existing Energy System	Hydrogen
Accessibility	●●	●
Flexibility	●●●	●●
Reliability:		
Now	●●	●
In the future	●	●●●
Acceptability, in terms of:		
Affordability	●●	●
Quality	●●	●
Environment	●	●●
Sustainability	●	●●

Key to symbols:
- ● Does not meet expectations
- ●● Expectations are partially met
- ●●● Meets expectations

Table 12.2 Current Evaluation of Hydrogen against the Existing Energy System and the Expectations of End Users

End User Expectations	Existing Energy System	Hydrogen
Accessibility	●●●	●
Ease of Use	●●●	●
Flexibility	●●●	●●
Convenience	●●●	●
Reliability:		
Now	●●	●
In the future	●	●●●
Consistency	●●●	●
Acceptability, in terms of:		
Affordability	●●	●
Quality	●●	●
Environment	●	●●●
Sustainability	●	●●●

Key to symbols:

● Does not meet expectations

●● Expectations are partially met

●●● Meets expectations

Table 12.3 Obstacles Facing the Deployment of Renewable Hydrogen in Sheffield

Stakeholder Expectations and Additional Issues	Obstacles
Accessibility	Lack of supply and demand for hydrogen and fuel cell technology
	Inaccessibility of local biomass resources for hydrogen production
	Lack of market for hydrogen and fuel cells
Ease of Use	Stakeholder unfamiliarity with the use of hydrogen as an energy carrier
	Stakeholder unfamiliarity with fuel cells and their applications within buildings
	Lack of infrastructure in place to buy and produce hydrogen and purchase fuel cells
	Need management and safety procedures like other fuels
Flexibility	Storage is needed at or near the point of consumption to ensure supply meets demand
Convenience	End users need to be reassured that any move towards a hydrogen economy will be convenient
Reliability	Supply of hydrogen must be reliable, both now and in the future
	Need to guarantee the supply of hydrogen
	Need to guarantee the performance of fuel cell technology, its installation, maintenance and operation
	Stakeholder confidence in hydrogen and fuel cells
Consistency	May involve end users in hydrogen production at or near the point of consumption
Acceptability	No grants are available to end users to utilise hydrogen and fuel cells for energy needs in buildings, on an individual, group or community level
	Need to guarantee the quality of hydrogen
	Need to guarantee the quality of service from potential hydrogen suppliers
Public Acceptance	Public acceptance may affect the utilisation of hydrogen and fuel cells in Sheffield
Transition Period	Need to put the infrastructure in place to produce and supply hydrogen to end users
	Need to establish if existing gas networks can be utilised to distribute hydrogen to consumers

13. EXPLORING THE SOLUTIONS

13.1 Influencing Stakeholders

If renewable energy technologies are going to be used to reduce local carbon emissions and contribute towards the development of a sustainable energy system in Sheffield, they must be technically and economically available, whilst meeting existing stakeholder expectations of energy services. As previous chapters have shown, the use of PSD, active solar systems, PV, wind power, biomass energy and small-scale hydro is technically possible in Sheffield. One reason for the low uptake of renewable energy resources and technologies lies with their ability to meet existing stakeholder expectations. Stakeholders, namely electricity and district heating suppliers and domestic, business and industrial end users, have a key role to play in the deployment of renewable energy technologies in Sheffield, especially as they are key decision-makers. Stakeholders can influence the success or failure of a new or existing product, technology or service through their purchasing activities. Depending on the stakeholder, it is important that renewable energy services meet existing expectations of accessibility, ease of use, flexibility, convenience, current and future reliability, affordability, quality and environmental and sustainability concerns. Although it is difficult to directly change the purchasing behaviour of stakeholders, the right conditions can be created in which stakeholders can be influenced to take positive action.

One approach to this problem is to ensure that renewable energy technologies perform as well as, if not better than, the existing energy system in supplying energy for use in buildings in Sheffield. In this respect, the performance of the existing energy system in meeting stakeholder expectations provides a 'yardstick' against which renewable energy technologies can be judged. This analysis, which has been undertaken in previous chapters, is summarised in Tables 13.1 and 13.2. Here, the performance of the existing energy system and renewable energy technologies against energy supplier expectations (Table 13.1) and end user expectations (Table 13.2) is illustrated. To ensure consistency with the previous analysis, a series of dots have been used to indicate where the existing system and renewable energy supply currently meet stakeholder expectations (three dots), partially meet expectations (two dots) and fail to meet expectations (one dot).

Table 13.1 Evaluation of Renewable Energy Technologies Relevant to Sheffield against the Expectations of Energy Suppliers and the Existing Energy System

Energy Supplier Expectations	Existing Energy System	Wind Power (Electricity)	Biomass Energy (District Heating)	Small-scale Hydro (Electricity)
Accessibility	●●	●	●	●●
Flexibility	●●●	●●●	●●	●●●
Reliability:				
Now	●●	●●	●	●●●
In the Future	●	●●●	●●●	●●●
Acceptability:				
Affordability	●●	●●	●●	●●
Quality	●●	●●	●●	●●
Environment	●	●●	●●	●●
Sustainability	●	●●	●●	●●●

Key to symbols:

- ● Does not meet expectations
- ●● Expectations are partially met
- ●●● Meets expectations
- \- Not applicable

As earlier analysis has shown, there is an element of uncertainty and lack of confidence associated with the ability of renewable energy to provide energy services. However, as Table 13.1 shows, the existing energy system is not perfect in meeting stakeholder expectations either. From the supplier perspective, there are problems associated with the accessibility of the resources used, the reliability of supply, and the cost and quality of resources. Additionally, there are questions over the future reliability of energy supplies, and the environmental and sustainability implications of current energy production. The low ranking of environmental and sustainability expectations also raises questions over whether or not energy suppliers are concerned about future energy supplies and the impact of energy production on the environment. Although energy suppliers may value resources as accessible, reliable, affordable and of sufficient quality now, mechanisms such as the Renewables Obligation may help to move environmental and sustainability issues higher up the agenda of energy suppliers. However, the Renewables Obligation is only likely to stimulate the use of local renewable energy resources for electricity production, as it does not cover heat production.

According to Table 13.1, wind power, biomass energy and small-scale hydro offer a reliable energy source in the future and perform as well as the existing system in meeting stakeholder expectations of affordability and quality. In particular, small-scale hydro technologies perform as well as, and even better than, the existing energy system in meeting all stakeholder expectations. However, there are still obstacles facing the refurbishment of existing sites in Sheffield as explored in Chapter 10. In relation to wind power and biomass energy, Table 13.1 shows that the accessibility of wind power and biomass energy resources and the flexibility of biomass energy supply are three key areas where renewable energy supply fails to perform as well as the existing energy system. If wind power and biomass energy are to perform as well as the existing system in meeting energy supplier expectations, it is in these three areas where solutions need to be focused.

From the end user perspective, Table 13.2 shows that the existing energy system performs well overall. However, whether the existing system actually performs well, or is perceived by end users to perform well, is debatable. How end users view or perceive the existing energy system has implications for the way end users view the provision of renewable energy services. End users may perceive that the existing energy system meets all their main requirements, namely accessibility, ease of use, flexibility, convenience and consistency. As such, they may feel that there is no need to switch to renewable energy technologies. For those who are motivated by environmental and sustainability concerns, renewable energy technologies are likely to be viewed more favourably. Although this may be true, research has shown that there is a gap between people's awareness of environmental issues and their purchasing behaviour (Hobson, 2001). Energy suppliers are driven by other motivations, such as the Renewables Obligation, increased environmental legislation and regulation, national and regional targets combined with existing concerns over the accessibility of resources, future reliability of supply, and cost and quality issues.

As Table 13.2 shows, in the view of end users, the existing energy system and renewable energy technologies perform well in contrasting areas. Where the existing system fails to meet end user expectations in terms of the future reliability of supply and wider environmental and sustainability issues, renewable energy technologies fully meets these expectations. Likewise, renewable energy fails to perform well in relation to accessibility, ease of use, flexibility, convenience and consistency. This suggests that when end users make decisions about energy services, they value accessibility, ease of use, flexibility, convenience, consistency, reliability, cost and quality over the

Table 13.2 Evaluation of Renewable Energy Technologies Relevant to Sheffield against the Expectations of End Users and the Existing Energy System

End User Expectations	Existing Energy System	PSD	Active Solar Systems	PV	Biomass Energy
Accessibility	●●●	●	●	●	●
Ease of Use	●●●	●	●	●	●●
Flexibility	●●●	●●	●●	●●	●●
Convenience	●●●	●	●	●	●●
Reliability:					
Now	●●	●	●●	●●	●
In the Future	●	●●●	●●●	●●●	●●●
Consistency	●●●	●	●	●	●
Acceptability:					
Affordability	●●	●	●	●	●
Quality	●●	●	●●	●●	●●
Environment	●	●●	●●	●●	●●●
Sustainability	●	●●	●●	●●	●●●

Key to symbols: ● Does not meet expectations

●● Expectations are partially met

●●● Meets expectations

future reliability of supply and environmental and sustainability concerns. Priority is focused on the immediate benefits of energy supply rather than considering current and future environmental and sustainability implications of their energy purchase and the future reliability of energy supply. Although renewable energy fails to meet many end user expectations, it is the interface between end users and energy utilities which is lacking, not the technology. End users expect to be able to ring up a utility and be connected to a service. With renewable energy, this service is unavailable at present unless end users purchase a green tariff. Therefore, it is the business structure which exists around the technology that is the issue.

It has been argued that if renewable energy technologies reduce in price and/or the price of energy continues to rise, more investment in these technologies is likely to take place. However, based on Table 13.2, it is debatable whether or not this would stimulate widespread end user, and possibly energy supplier, interest in renewable energy technologies. Not only is cost an issue, but the accessibility of energy supply and the technologies, the ease of use of new systems, the flexibility of supply and the convenience of the conversion to new systems are also important considerations facing end users/ decision-makers. The relatively poor performance of renewable energy technologies in meeting current end user expectations of accessibility, ease of use, flexibility, convenience and consistency, indicates that even with rising energy prices, end users might not be confident to invest in renewable energy technologies.

It appears that the key to the problem is to explore ways in which certainty and confidence can be developed amongst stakeholders. In addition, thought needs to be given as to what motivates and drives stakeholders into making decisions. Although cost is an important consideration, many actions are needed to ensure that renewable energy meets other stakeholder expectations whilst ensuring that the practical benefits of renewable energy technologies are realised within Sheffield. The following sections suggest possible solutions that could be used to stimulate and increase the use of renewable energy by energy suppliers and end users in Sheffield. The solutions are subdivided into three broad categories, namely land use planning (Section 13.2), building stakeholder confidence (Section 13.3) and increasing supply and demand (Section 13.4). The utilisation of renewable hydrogen is discussed in Section 13.5, followed by a discussion of the need to import additional renewable energy supplies to meet Sheffield's energy needs (Section 13.6). The suitability of the measures to encourage the wider deployment of renewable energy technologies in Sheffield are evaluated against the stakeholder demand criteria in Section 13.7.

13.2 Land Use Planning

13.2.1 Energy Plans

As examined above, wind power fails to meet energy supplier expectations of accessibility. At present, the accessibility of the wind resource in Sheffield is limited due to conflicts between the potential siting of wind turbines and site availability. One solution would be to develop an energy and implementation plan for Sheffield. Energy plans have been produced for various cities across Europe (Kelly and Mortimer, 1996). In the UK, energy plans for local authority areas are less common although some work has been undertaken in producing and implementing community energy plans, for example, in Newcastle, Leicester and the North York Moors National Park (Newcastle City Council, 1992; Leicester City Council, 2004 and SDC, 2004). Producing an energy plan for Sheffield would require a more pro-active approach from Sheffield City Council in addressing and tackling local energy and carbon emission issues.

An energy plan covering the whole of the district would allow energy and carbon emission issues to be identified and addressed as part of an ongoing programme. This would require a joint effort from both Sheffield City Council and the Peak District National Park. Although both of these Authorities are planning authorities in their own right, there needs to be some common approach in addressing the issue of renewable energy developments in the area of overlap between them. Ideally, specialist input would be required to work with the local community to develop the energy plan and support the local community in pursuing sustainable energy development within Sheffield. It is important that the onus for the development of the plan and its implementation rests with the local community with local authority specialist support and guidance for the process. Identifying local people as champions to lead and take the plan forward would help to ensure that the ownership and implementation of the plan are community led. In addition, having local champions and ownership of renewable energy schemes allows local people to weigh the benefits of the development against any disadvantages such as visual impacts of wind turbines and roof mounted solar water heating and PV panels.

An energy plan could also solve problems of accessibility for wind power and other renewable energy sources in Sheffield. In much the same way as minerals plans are designed, an energy plan could be produced which identifies a general area of search. By adopting this method, general areas where a wind resource, small-scale hydro resource, solar energy resource and/or a potential biomass energy resource could be identified. As with minerals planning, a presumption in favour of wind development, or other renewable energy development, could be granted. Designations of areas for prospective utilisation would help to increase the accessibility of wind power and small-scale hydro sites by energy suppliers and open up opportunities for the utilisation of solar and biomass energy resources by end-users. However, such an energy plan would need to be integrated and supported by planning policies and local plans.

13.2.2 Energy as a Material Consideration

There will always be pressures on urban land use as land is in short supply and there are competing demands for land within cities. The key is to manage the available land in the best possible way for the city. A task which is, in essence, the role of planning within local planning authorities. However, if Sheffield is committed to sustainable energy development based on renewable energy, it could be argued that sites, which are particularly suited for site-specific renewable energy developments, such as wind power, should be allocated accordingly. At present, energy use is not considered as a material consideration for development. Although previous planning policy guidance in the form of PPG12 set out the need for local authorities to consider energy use in their local plans, this national policy has not been widely applied on a local level. The revised PPG12, referred to as PPS12, advocates the development of new types of local plans in which energy should be a material consideration. PPS12 again places the onus on local authorities to put this policy into practice on a local level. In light of the revised PPS22 on renewable energy, combined with national and regional targets for increasing renewable energy production and lowering carbon emissions, local authorities may be more motivated to consider energy as a land use category. In order to help to ensure that local authorities address this, it may be possible for national government to ask local authorities to provide evidence of their adherence to this national policy.

Making energy use a land use category in local plans would help renewable energy developments take place on a local level. Allocating specific sites for wind power generation within a city or district would be a positive step forward in developing a sustainable local energy system based on local renewable energy resources. In addition, it would mean that local people would have to address the environmental impacts, both positive and negative, of having local energy generation plants within the city. If the use of land for energy development is not considered in land use plans, prime sites could be lost. This would have long term implications on the ability of Sheffield to reduce carbon emissions within the district and move towards the wider utilisation of local renewable energy resources. Sheffield would also continue to be reliant upon importing energy supplies, whether they are from renewable or non-renewable energy sources. Generally, local authorities need to adopt a more pro-active approach to land management, particularly as carbon emission targets have been set by the national government. If delays towards utilising local renewable energy resources continue, more pressure is placed on areas to achieve reductions in carbon emissions in shorter time-scales. This may result in some inappropriate developments that could have been avoided by better planning and a long-term view of energy provision within the city.

13.3 Building Confidence Amongst Stakeholders

13.3.1 An Integrated Approach

Amongst energy suppliers and end users, there is a need to remove uncertainty when it comes to utilising renewable energy resources. Overall, there is a lack of confidence throughout the supply chain. Stakeholder unfamiliarity, lack of knowledge and understanding of renewable energy technologies, the operation of systems, access to information and advice, and awareness of grant availability are key barriers facing the uptake of renewable energy technologies in Sheffield. In addition, there is a lack of infrastructure in place to guarantee the performance of the technologies and their energy supply, and promote, sell, buy, install and maintain renewable energy systems. This situation is particularly relevant to the utilisation of biomass energy in Sheffield although similar obstacles also affect other renewable energy technologies. The influence of these obstacles are reflected in the poor performance of renewable energy technologies against stakeholder expectations of accessibility, ease of use, convenience, reliability and affordability in Tables 13.1 and 13.2. For many stakeholders, renewable energy technologies are different from conventional ways of providing heating, cooling, lighting and ventilation. Stakeholders need to be reassured that renewable energy is viable and can supply energy services that are accessible, easy to use, flexible, convenient, reliable, consistent and acceptable. There are a number of possible solutions that could be put in place to promote confidence in renewable energy technologies amongst stakeholders. Advertising and marketing, education and training, supporting infrastructure and demonstration, standardising products, providing guarantees and certification, and integrating renewable energy technologies into conventional building work are key areas where improvements would be beneficial. Although the solutions are discussed under each of these headings below, an integrated approach is needed to help ensure that confidence, knowledge and understanding is developed and expanded amongst all stakeholders.

13.3.2 Advertising and Marketing

Better promotion of renewable energy products, technologies and services is needed. Although there are many factors that affect the success or failure of a new technology or energy service, targeted and well thought out advertising and marketing plays a key role. With renewable energy technologies, the level of knowledge about their characteristics and applications varies greatly. People are likely to be unaware of them, have limited knowledge or believe the myths. Common myths surrounding renewable energy act as a barrier to their acceptance and utilisation. For example, the level of bird kill with wind turbines is often quoted and not set in context and compared with other aspects of life which kill birds on a regular basis such as cats and cars (Home Power, 2004). The myths need to be dispelled and people's level of awareness and information about renewable energy and its applications needs developing and promoting. Unfamiliarity and lack of information on renewable energy applications leads to uncertainty and lack of consumer confidence in the technologies. It can also lead to the mis-management of installed renewable energy systems.

Before any advertising and marketing campaigns begin, it is necessary to establish the motivations of end users. Many studies have been undertaken by companies and organisations to try to understand the purchasing behaviour and needs of their customers or potential customers (including MORI, 2002 and Customer Champions, 2003). However, energy is a difficult area in which to try and identify motivations of end users. As previously proposed, end users are motivated by accessibility, ease of use, flexibility, convenience and consistency of energy services. However, people's level of interest in energy ranges from a detailed understanding of how energy is delivered, distributed and used in a building to those who simply expect the lights to come on when they flick a switch. Although there are many diverse and changing motivations of stakeholders, it would be fair to contend that most people expect a certain level of comfort within a building and the freedom to use appliances, machines or machinery on demand. It could be these areas in which advertising and marketing need to be focussed. As previously examined, end users who are motivated by environmental and sustainability concerns are more likely to invest in renewable energy technologies. For those who are not motivated by environmental and sustainability concerns, advertising and marketing must firstly be directed towards non-environmental concerns in order to stand any chance of success, before promoting the environmental benefits of the technology. If the general environmental awareness of end users is going to be raised, environmental links need to be in place to trigger connections in the mind of the stakeholder.

Advertising the non-energy benefits of using renewable energy technologies is beginning to appear in the promotion of green buildings. One example is a recent mill conversion in Huddersfield, West Yorkshire, which has been developed using energy efficiency measures, a wood-fuel heating system and PV panels (Anon, 2004a). The luxury of the apartment combined with SMART technologies including ceiling speakers, plasma screens, audio sound in every room, security systems, programmable curtains, blinds and shutters, digitally programmable lights and heating, and the ability to programme this from anywhere in the world were the main focus of the advertisement. Secondly, the green technology, low energy bills and a clean environment were given priority over advertised examples of the luxury lifestyle that one could obtain by using the mills facilities including a restaurant, bars, spa, pool, gymnasium and bistro. The price range of the apartments was listed last (Anon, 2004a). As such, the advertising focuses on the comforts of the home and the lifestyle associated with living in the building. End users can have all of this and advanced technologies to control the heating, cooling, lighting, ventilation, as well as being environmentally friendly. In this way, renewable energy technologies have been integrated into a complete "lifestyle" package. This approach is similar to that of car advertising where the lifestyle of travelling on the open road surrounded by beautiful scenery and/or attractive people is used as a key selling feature. Again, this implies that, although renewable energy technologies are available, it is the infrastructure around the technologies which is lacking. In addition to the need to incorporate renewable energy technologies into a lifestyle package and make them attractive, other advertising techniques could be utilised for the promotion of renewable energy. One example is product association, which can be a powerful tool in the success of a product, technology or service. The use of catchy slogans or tunes could help place renewable energy and what it offers in the minds of stakeholders.

Advertising and marketing needs to be part of a wider and ongoing renewable energy programme within the UK rather than the ad hoc approach currently taken. This would help to ensure that people understand and continue to be aware of the options and opportunities available to them particularly as these are likely to change over time. In addition, opportunities could also be developed to increase the profile of renewable energy by having large, city centre examples. A current example of this is the proposed refurbishment of the Co-operative Insurance Society (CIS) building in Manchester. The CIS has recently put in a planning application to have the 28 storey building clad in PV panels in a mosaic style in keeping with the original mosaic pattern of cladding initially used on the building (Kellett, 2004). At present, this building is a landmark building as it is the tallest in Manchester. Clad in PV panels, it could become an icon for PV technologies and would also provide a good example of how PV panels could be utilised and integrated within existing buildings in cities. In addition to the CIS building, more examples are needed to show how renewable energy can be used in an urban environment and to illustrate that they can be used in visually creative ways.

13.3.3 Education and Training

Education is an important means for increasing people's awareness and knowledge about the environment in general and specific issues, such as renewable energy applications. However, the extent to which education, in the traditional sense, reaches the majority of the population is debatable. Educating the young is an important part of increasing environmental awareness. For those who do not come into contact with children, this approach is limited. One suggestion would be to hold seminars and training sessions for adults run by organisations such as the Yorkshire Renewable Energy Network, Community Renewables Initiative, environmental consultancies and local authorities. However, who has the time or inclination to attend such events and how would people hear about them? As such, the advertising of such events needs to be targeted at people in local communities. In addition to traditional ways of educating people, existing and new ways of interacting and communicating with people need to be tapped into. In this context, it should be noted that individuals receive information from a wide range of sources, including:

- Television and radio – terrestrial and digital channels, news and non-news programmes, adverts,
- Advertisements – on the train, tram, roadside billboards, bus stations, street advertising, newspapers, magazines, TV, the internet, T-shirts, etc.
- Word of mouth,
- Articles in newspapers and magazines,
- The internet,
- Shops,
- Trades people – plumbers, electricians, etc.
- Education – schools, university, museums, and
- Cultural pursuits - galleries, theatre and the cinema.

There are many opportunities to utilise these areas to increase the coverage of renewable energy options, for example, showing advertisements or short educational films before films at cinemas. Another option would be to develop programmes, which increase the awareness of stakeholders. These programmes could be driven by national government in combination with local authorities, regional agencies, local businesses and groups and companies who sell renewable energy technologies. Significant funding would be needed to do carry out this programme on a national scale. However, other national programmes, such as increasing people's IT skills, have been successfully deployed on a local level. A different range of programmes could be implemented ranging from increasing people's basic awareness to producing business or community plans which focus on reducing energy use through energy efficiency measures followed by an increased use of renewable energy technologies. This would also tie in with the introduction of energy plans through the land use planning process, as discussed in Section 13.2.1.

Trades people, such as plumbers and electricians, are important contacts for information and advice on energy services. As such, they have an important role to play in the deployment of renewable energy technologies in Sheffield. However, at present, there is a shortage of plumbers, which would present more problems for the installation of certain types of renewable energy technologies. It is likely that plumbers and electricians would favour work, which is quick to undertake, and pays well. For those who are not trained or do not have much experience in installing solar hot water or PV panels, they may perceive its installation as time consuming and give preference to other work. However, if renewable energy technologies are advertised and promoted, this may lead to an increase in demand for the technologies. As such, business opportunities for skilled trade's people in renewable energy applications are likely to emerge. Other shortages in skills, such as the shortage of teachers and plumbers, have gained attention and investment. For plumbers in particular, apprenticeship programmes have been set up to address the national shortage. The apprenticeship programme could be extended to train people to install renewable energy technologies, such as solar hot water and PV panels. Funding could be provided for people who undertake the courses and set up businesses or join companies installing renewable energy technologies.

One concern, particularly amongst end users, is the level of interaction involved with renewable energy options. Although some end users may wish to get involved in community renewable energy schemes and become local champions, other people may want the benefits without directly being involved. At present, there are few, if any companies who offer a comprehensive renewable energy package for end users. For example, if the owners of a terrace of buildings wanted to put a group heating system, how would they go about it and whom would they contact? Ideally, a company is needed to come in, sign people up and undertaken the project management. As such, people would get the benefits of renewable energy without having to get involved in the detail of, for example, seeking grant availability, submitting planning applications, sorting out legal contractual negotiations and organising general site management during installation.

The building industry perceives renewable energy technologies as a risky investment and buildings which incorporate these features are felt to be difficult to sell. However, the new building regulations, in which the energy performance of new and retrofit buildings is an intrinsic element, will help to stimulate change in this area. The building industry response to the new regulations may help to drive local changes in the way renewable energy technologies are viewed and utilised. In particular, the use of PSD features could become more widely incorporated into building work as a consequence of such building regulations. Depending on their success, future building regulations might attempt to encourage more radical approaches which promote renewable energy technologies even further.

13.3.4 Supporting Infrastructure and Demonstration

One of the key problems which renewable energy technologies face in addition to advertising, marketing and education is that there is limited infrastructure in place through which stakeholders can pursue renewable energy technologies. As noted earlier, there are few places where stakeholders can view the different varieties of renewable energy technologies in Sheffield. One of the few options would be for the stakeholder to look on the internet, but even here, there are few websites which provide details on the technologies for the consumer. For websites which supply advice on renewable energy technologies, such as the Save Energy Website, stakeholders need to know that such sites exist and where to access them (Saveenergy, 2004). Whatever the approach, the accessibility of information for stakeholders is limited. One solution would be to open up showrooms within cities in which stakeholders could view and discuss renewable energy technologies with professionals. In London, Solar Century, a PV supplier in the UK, has a showroom. However, it is questionable as to how many stakeholders from Sheffield would wish to travel to London to see solar technologies. By opening up a showroom in Sheffield, there may be opportunities for businesses to rent space for their own technology or for a new business to set up that trades in a variety of technologies. Although there are some limitations to this, for example, having a large wind turbine on site, with imagination and the use of different media, this problem could be overcome. In addition, it is important that expert advice is available to stakeholders, which is communicated in a non-technical way. This advice needs to be clear and straightforward and be able to answer the many diverse questions that end users are likely to have. Also, there is likely to be a need for expert help in matching the supply of energy from renewable energy technologies to existing demand within buildings together with the tools required by end users to carry out their own assessments.

Another option would be to sell renewable energy technologies alongside their existing counterparts. This is already done to some extent when stakeholders wish to purchase a new fireplace from a specialist shop. Here, electricity, gas, solid fuel and wood-fired heating stoves can be viewed in some shops. Integrating renewable energy technologies with existing options would provide consumers with the opportunity to view alternatives that they may not otherwise consider. This could also be expanded to include energy efficiency measures. This would improve the accessibility of renewable energy technologies by providing information, advice from professionals and the demonstration of technologies all in one location.

13.3.5 Standardising Products

Using biomass energy is an unconventional way of heating buildings. Although biomass, in particular wood, has a long history of use in the UK, natural gas and electricity have taken over from the use of wood since the Second World War. Returning to the use of wood as a fuel within buildings will require more involvement from end users than with conventional energy supplies. There are ways of making the interaction between the fuel and the end user easier. Wood, for example, can be processed in a variety of ways which help to ease the handling of the wood, and the advancement of technologies has helped to create a more efficient combustion process. Depending on the type of wood-burning equipment in use, the processing of wood into chips, pellets or briquettes ensures a consistent (standard) product for the end user. By creating a standard product, the energy content, moisture content and size of the product could be controlled and assured to help develop end user confidence in the product.

13.3.6 Guarantees and Certification

One issue common to PSD and active solar systems is the lack of quality assurances that the technology will perform according to end user expectations. One solution to this would be to develop and establish technology standards, logos and guarantees. Similar to other products on the market, a product guarantee will help to ensure that the technologies perform correctly over the warranty period. Although product guarantees are important, it may also be necessary to extend these to cover the installation and maintenance of the product. In addition, logos and standards act as important measurements of the quality of a product and service and guarantees that the product performs correctly. Energy efficiency recommended labels have already been produced for approved appliances and the use of the EU Energy Label is a legal requirement for retailers, mail-order companies and manufacturers who must display the energy rating of domestic appliances (Saveenergy, 2004). As such, producing a certification system with logos for renewable energy technologies may be the next step. Under some existing funding schemes, such as the Clear Skies Programme, accredited suppliers and installers must be used. This could be expanded into a nationally based system, which lasts beyond the end of these funding programmes.

In addition to developing product guarantees and certification schemes, it is important that such measures are communicated to stakeholders to avoid confusion and dispel any myths which may develop. In the case of burning wood in smokeless zones, confusion over whether this is legal has developed. Wood can be burnt in smokeless zones provided that approved wood burning appliances are used. This uncertainty may lead to some end users deciding not to utilise wood for energy needs within buildings, as they may feel that they are breaking the law. Although approved appliances are available, better communication to end users is required to dispel the myths.

13.3.7 Integrating Building Work

Adding any feature to an existing building will cause disruptive and inconvenient building work during construction. The same considerations apply to the installation of renewable energy technology on a building. One way of overcoming this obstacle is to incorporate, simultaneously, such installations into other building work to minimise disruption. It may also be possible to sell solar energy technologies as part of re-roofing work or when adding extensions onto existing buildings. In addition to reducing the amount of construction needed, it could also reduce costs. Although this would provide an ideal package, this pre-supposes knowledge on behalf of builders and end users. If builders are resistant to change and end users are unaware of the possible opportunities, it is unlikely that such developments would take place. This highlights the need for a new set of skills and trades in providing integrated building packages incorporating renewable energy technologies. As such, the opportunity may exist for a company or organisation to bring this all together and integrate existing building practices with renewable energy technology retrofits.

Resistance to change and unawareness of the possibilities can be illustrated by the limited application of PSD features on buildings in the UK. Although there has been an uptake in the number of conservatories added to domestic buildings in recent years, other PSD features such as Trombe walls are less common. By improving people's general awareness and knowledge of PSD opportunities and identifying opportunities for development in energy plans and other policy documents, is likely to increase people's familiarity with PSD. Additionally, having access to professionals who can offer sound advice and guidance will help the wider use of PSD in buildings. Used together, these measures may lead to an increased demand for PSD and precedent being set locally. Careful and creative design will also help in the uptake of PSD in Sheffield and the UK.

13.4 Supply and Demand

13.4.1 Renewables Heat Obligation

Currently, the lack of supply and demand for biomass energy limits the accessibility of this resource for energy suppliers. At present, there is neither demand nor incentives for district heating suppliers to invest in biomass energy. Although some waste biomass is mixed in existing municipal waste streams, no additional biomass is used in Sheffield. One solution would be to extend the Renewables Obligation to cover district and group heating developments. Groups, such as Friends of the Earth, who have suggested the need for a Liquid Biofuels Obligation, have also proposed the idea of a Renewables Heat Obligation (FOE, 2003; ENDS, 2004 and RPA, 2004). The Renewables Obligation, as discussed in Chapter 8, is a market mechanism which has created a market demand for electricity produced from renewable energy sources in the UK. By extending the obligation to cover heat, this would help to create a demand for biomass by district heating suppliers and may also generate further interest in biomass-fired district heating within other communities across the UK. By creating a demand for biomass on a large-scale within a city such as Sheffield, a supply can be created within the district and surrounding areas. In addition, this would help to stimulate the market for biomass beyond the existing demand for straw and some wood chip, increase investment whilst creating a more secure investment for farmers in biomass and reduce risks.

If a Renewables Heat Obligation came into effect, this would create a market for the use of biomass and, possibly, active solar hot water systems for heating purposes. Opportunities could develop for biomass and/or active solar systems to develop on an individual building, group or district-heating basis. In addition, the opportunity to obtain Renewable Obligation Certificates for heat production may stimulate investment in this area. Apart from district heating, heating of business, industrial and domestic buildings are often carried out by the owners or occupiers. Developing heating systems in which traditional heat suppliers and end users interact more closely will require a different management approach. This is discussed in more detail in Section 13.4.5.

13.4.2 Renewables Electricity Obligation

PV panels are currently an expensive way of generating electricity. Although one benefit of PV is that any excess electricity generated can be sold back to the grid, the price paid by the electricity utility is lower than the price the end user pays per unit of electricity from the grid. Although Renewable Obligation Certificates can help to increase the price per unit of electricity sold to the grid, a scheme must generate more than half a megawatt hour of electricity per year to be eligible. As such, this is having an impact on the use of a range of renewable energy technologies by the small-scale user. The government is currently investigating the possibility of lowering this limit to accommodate small-scale electricity generation from renewable energy technologies such as PV and small wind turbines (Powergen, 2004). In the meantime, one option would be to group sites together so that the combined amount of electricity produced by the whole scheme would be eligible for the certificates.

13.4.3 Fiscal Incentives

At present, there are high capital costs involved when investing in renewable energy technologies. Ideally, a financial market mechanism is needed to boost the uptake of renewable energy technologies in Sheffield and the UK. However, as this is unlikely to happen, there are other fiscal incentives which could be introduced to lower costs. At present, there are a number of grants available for individual and community-based renewable energy applications, with the exception of PSD. It could be argued that a PSD grant system is needed. One of the problems in developing such a system is defining PSD and the products that would fall under its remit. As examined in Chapter 5, PSD covers a wide range of technologies ranging from inserting phase changing materials into existing walls for enhancing natural heating and cooling to adding glazed areas such as conservatories and atria. In the development of such a grant scheme, questions would need to be addressed regarding whether grant funding would be made for conservatories or whether the grants should be concentrated on less common PSD technologies in the UK, such as Trombe walls. Part of the problem facing PSD is that it is the "poor relation" of solar energy technologies in the UK. PSD is more complicated than active solar hot water and PV panels. Active solar and PV panels are usually a simple "add on" feature. As such, PSD opportunities and features need to be recognised and promoted both in Sheffield and on a national level. This could be achieved through applying many of the suggestions outlined here. Other mechanisms such as tax breaks and reducing VAT payments on renewable energy technologies could be used. In relation to VAT payments, VAT could be added to the technologies on an incremental basis over a set period. Tied with educational programmes and advertising and promotional campaigns, this may help to stimulate wider investment in renewable energy technologies, particularly in the domestic market.

13.4.4 Supply and Demand Management

Supplying electricity from a single PV panel onto the existing electricity grid would not be problem for an electricity company and network operator. However, if a large number of owners of suitable business and industrial buildings in Sheffield decided to invest in PV, this would create a potentially large body of distributed generators. Distributed energy generation is unconventional when compared with the existing production and provision of energy in the UK. Distributed energy generation would demand the creation of a new kind of energy utility, or a number of utilities, which would have to manage supply and demand within the district.

In addition to looking at supply issues from the perspective of the energy supplier, they would need to look at supply from the perspective of new energy suppliers i.e. end users. They would need to manage a diverse group of energy suppliers and different levels of supply within the district. Their level of support may extend to advising potential suppliers on the opportunities which would be open to them. In addition to managing internal supply and demand, they would also be responsible for managing imported energy to the district. One suggestion is that the energy utility could take the form of an Energy Service Company (ESCO) whereby individual end users are linked to a single local energy supplier (Clemitshaw, 2002). Operating as a community-based venture, ESCO's could supply energy to meet local needs. This mechanism could be used to secure energy supplies, alleviate issues of fuel poverty, promote energy efficiency and reduce carbon emissions.

New energy utilities or ESCOs may become involved in sorting out issues such as "who owns the roof" when active solar systems and PV panels are added to existing roofs. There are many possible scenarios whereby solar systems could be installed on buildings and provide energy services to adjacent buildings, or in the case of PV, electricity could be supplied directly onto the national grid. Although changing roof ownership in relation to solar energy technologies is a relatively new idea in the UK, developments have taken place elsewhere in Europe. In Amersfoort near Amsterdam, for example, a system has been developed whereby the electricity utility, REMU, installed PV panels onto domestic roofs. For a ten-year period, REMU rent the roof space, maintain the PV system and the electricity produced by the panels goes directly onto the grid. After ten years, the ownership of the PV panel transfers to the building owner (Leeman, 2004). Introducing a similar system in the UK would require relationships between energy utility suppliers and end users which are different from current arrangements. Traditionally, energy suppliers have provided end users with energy rather than entering into a relationship whereby distributed energy generation, using renewable energy technologies installed on individual buildings, forms an important part of meeting the energy needs of a community, specifically, and the UK, generally. Entering into such a relationship, particularly in relation to electricity generation, would need to benefit both electricity suppliers and end users. Whilst arrangements with one-off buildings may not be of interest to electricity suppliers, a large number of buildings may be. For end users, the income received from renting the roof space could help offset investment costs. This would also result in lower electricity prices for the end user. There may also be opportunities for the owner of the system to enter into a contractual agreement if the energy is supplied to neighbouring buildings. In this case, costs could be added to the price of such energy for the use of the roof space and any maintenance of the system.

In a wider context, ownership issues also affect the utilisation of small-scale hydro sites. Conflicts with surrounding land use and risk of flooding may constrain the development of some hydro sites. Additionally, the ownership of land on which hydro power plant is to be built needs to be determined. This is also an issue which affects other renewable energy technologies such as wind turbines, which may be sited on private or public land. Negotiations and contractual agreements will need to be entered into to ensure the site or resource can be exploited legally, for example, obtaining abstraction licences in the case of hydro sites. These negotiations could be entered into by the new energy utility or ESCO, which would specifically benefit those end users who would not wish to become directly involved in energy production.

13.5 Renewable Hydrogen

"Renewable hydrogen," produced from renewable energy sources, offers an environmentally friendly and sustainable energy way of providing stakeholders with key energy services in Sheffield. However, there are questions over the local production and supply of hydrogen and its wider application in buildings. Similarly to renewable energy technologies, renewable hydrogen fails to perform as well as the existing energy system in meeting both energy supplier and end user expectations, as illustrated by Tables 13.3 and 13.4, respectively. The poor performance of renewable hydrogen in this regard is due to the general problems facing renewable energy, such as accessibility issues, and problems surrounding the technical and economic status of hydrogen technology at present. The production of renewable hydrogen is unlikely to be available in the short to medium term. Additionally, there may be problems of supply. Hydrogen produced from renewable energy resources will depend upon excess supply from such sources. Otherwise, it will be necessary to decide whether local renewable energy resources will be used directly in Sheffield or for hydrogen production purposes. Given that end use technologies and energy systems operate with established energy carriers, especially electricity, it could be argued that it would be more suitable for local renewable energy resources to meet existing needs directly rather than be used to produce hydrogen. In addition, domestic and non-domestic products that run on hydrogen have not been developed and tested for wide scale use within cities.

Many problems facing renewable hydrogen as an energy carrier are similar to those facing renewable energy technologies as sources of energy supply. Obstacles include the lack of supply and demand for hydrogen, the unavailability of grants, and the infrastructure needed to buy and sell technologies, guarantee the performance of technologies and manage the local environmental impacts of hydrogen production. In addition, stakeholders are unfamiliar with using hydrogen as an energy carrier, which may lead to lack confidence in hydrogen. As such, many of the solutions suggested elsewhere, could also be extended to include the promotion of renewable hydrogen, when the time comes. Further research and development is needed on essential issues such as the transmission and distribution of hydrogen in existing pipelines, the creation of new pipeline networks and the performance of hydrogen end use equipment and appliances, particularly fuel cells. A tremendous commitment is required to transform hydrogen from the research and development phase to the commercial phase where it is used by end users in much the same way as they use natural gas today. Consequently, renewable hydrogen may become regarded as a longer term option.

Table 13.3 Evaluation of Energy Carriers against the Expectations of Energy Suppliers and the Existing Energy System

Energy Supplier Expectations	Existing Energy System	Renewable Hydrogen
Accessibility	●●	●
Flexibility	●●●	●●
Reliability:		
Now	●●	●
In the Future	●	●●●
Acceptability:		
Affordability	●●	●
Quality	●●	●
Environment	●	●●
Sustainability	●	●●

Key to symbols:

● Does not meet expectations

●● Expectations are partially met

●●● Meets expectations

Table 13.4 Evaluation of Energy Carriers against the Expectations of End Users and the Existing Energy System

End User Expectations	Existing Energy System	Renewable Hydrogen
Accessibility	●●●	●
Ease of Use	●●●	●
Flexibility	●●●	●●
Convenience	●●●	●
Reliability:		
Now	●●	●
In the Future	●	●●●
Consistency	●●●	●
Acceptability:		
Affordability	●●	●
Quality	●●	●
Environment	●	●●●
Sustainability	●	●●●

Key to symbols:	•	Does not meet expectations
	••	Expectations are partially met
	•••	Meets expectations

One key issue which could be addressed is safety and its perception. It is likely that when people think about hydrogen they recall the Hindenberg disaster in 1937 and believe it to be a dangerous, explosive fuel. With other energy carriers, education and regulation have played an important role in reducing accident numbers and ensuring safety for end users. If renewable hydrogen has a part to play in the future energy provision in Sheffield, education, training and regulation need to be extended to cover hydrogen. In addition, pilot studies and demonstration projects would need to be developed to overcome any negative public perceptions. Hydrogen demonstration projects are already taking place, particularly in relation to the use of hydrogen in fuel cells for transport applications. In a recent study of the use of hydrogen in fuel cells in black taxicabs in London, driver reactions to the vehicles and their performances were investigated. The study concluded that, if packaged as a financially attractive option, then drivers would be willing to drive renewable hydrogen vehicles. Additionally, the high degree of vehicle regulation in the taxi industry meant that the drivers did not view hydrogen fuel cells as unsafe as they had been approved. In a wider context, drivers were more concerned about their personal safety out on the road with regard to risks, for example, from theft and stabbing. The study concluded that if other professional areas were highly regulated and renewable hydrogen was regulated too, this might eliminate concerns over safety.

13.6 Importing Renewable Energy Supplies

As raised in Chapters 3 and 4, local renewable energy resources in combination with energy efficiency measures could only meet 47 % of the current energy demands in Sheffield. Although this would have a significant impact on reducing carbon emissions, Sheffield would continue to rely on imported energy to meet its remaining energy needs. In order to have a completely sustainable energy system in Sheffield and eliminate carbon emissions, any imported energy would need to come from sustainable renewable energy resources. In order to achieve international and national carbon emission targets across the UK, other urban and rural areas would need to work towards establishing their own sustainable energy systems based on energy efficiency and renewable energy resources. In this scenario, there would be a series of locally-based networks of distributed energy generation in combination with centralised energy schemes such as wind farms and wood-fired plants. Under these circumstances, energy utilities, as managers of the balance of supply and demand would have to oversee a diverse range of locally-distributed and centrally-based energy plants. Although some areas would be able to meet all of their energy needs using local resources, other areas like Sheffield, would also rely on the importation of renewable energy carriers. The development of such a system of management might be encouraged by enabling cities, such as Sheffield, to buy and sell carbon emissions in an effort to reduce local carbon emissions and meet national targets.

13.7 Evaluation of the Solutions

In order to consider whether the solutions suggested here may be suitable measures for promoting renewable energy technologies in Sheffield, Table 13.5 provides an initial indication of where each measure may have an impact on the stakeholder criteria. Table 13.5 clearly shows that, taken together, the measures proposed cover all of the criteria. There are no gaps where stakeholder expectations have failed to be addressed. This brief assessment has illustrated that each solution may have an impact on more than one stakeholder expectation. This can be illustrated by the example of the proposed introduction of a new system of supply and demand management. This system is likely to increase the accessibility, ease of use, flexibility, convenience, reliability, consistency and acceptability of renewable energy technologies. However, this measure alone is unlikely to achieve complete change. It needs the support of other measures, in particular advertising, education, training, the design and implementation of energy plans by local community champions, changes in the Renewables Obligation and other fiscal incentives. Such partial impact of individual solutions is true of all of the measures listed in Table 13.5. This emphasises the need for an integrated approach to be adopted which draws on each of the solutions suggested. Whether such measures could be delivered collectively by means of an integrated approach or whether they would conflict is, of course, open to question. Despite this, Table 13.5 indicates the potential of the measures put forward as practical ways of promoting renewable energy technologies in urban areas.

Table 13.5 Evaluation of the Coverage of Proposed Solutions on the Promotion of Renewable Energy Technologies in Sheffield

Possible Solutions	Stakeholder Expectations										
	Accessibility	Ease of Use	Flexibility	Convenience	Reliability		Consistency	Acceptability			
					Now	In the Future		Affordability	Quality	Environment	Sustainability
Energy Plans	✓				✓	✓				✓	✓
Energy as a Material Consideration	✓				✓	✓				✓	✓
Advertising & Marketing	✓	✓		✓	✓	✓				✓	✓
Education & Training	✓	✓	✓	✓	✓	✓				✓	✓
Supporting Infrastructure & Demonstration	✓	✓	✓	✓	✓	✓				✓	✓
Standardising Products		✓	✓	✓	✓	✓	✓		✓	✓	✓
Guarantees & Certification		✓			✓	✓	✓		✓	✓	✓
Integrating Building Work	✓	✓	✓	✓	✓	✓		✓	✓	✓	✓
Renewables Heat Obligation	✓		✓		✓	✓		✓	✓	✓	✓
Renewables Obligation (electricity reforms)	✓		✓		✓	✓		✓		✓	✓
Fiscal Incentives	✓		✓		✓	✓		✓		✓	✓
New Energy Managers	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓
Hydrogen R&D	✓	✓				✓			✓	✓	✓
Regulate Hydrogen		✓	✓	✓		✓	✓		✓		

Key to symbol: ✓ The measure could address this issue

14. CONCLUSIONS AND RECOMMENDATIONS

14.1 Conclusions

Within the current context of the UK's commitment to reducing greenhouse gas emissions, especially carbon emissions, a clear understanding of the nature of the problems, obstacles and complexities facing the deployment of renewable energy technologies in urban areas is urgently required. By using Sheffield as a case study example, practical ways in which renewable energy technologies could be used to reduce local carbon emissions and achieve sustainable energy systems within the urban environment have been examined. This investigation began by examining the interaction between the existing energy system, its energy suppliers and end users, and its ability to meet the energy expectations of these stakeholders. Means of evaluating the performance of the existing energy system against stakeholder expectations have been devised and it has been found that expectations vary depending on the type of stakeholder. Energy suppliers are motivated by expectations of accessibility, flexibility, reliability, affordability, quality and environmental and sustainability concerns. In addition to these particular expectations, end users place additional emphasis of ease of use, convenience and consistency on the energy services they receive. By assessing the existing energy system against these expectations, it was concluded that the existing energy system is not perfect. Specifically, doubts are raised about the ability of the existing system to produce and supply energy in an environmentally sustainable way whilst, simultaneously, continuing to provide stakeholders with key energy services into the future. As an alternative, it has been suggested that renewable energy technologies can address concerns over future environmental sustainability. However, this begs the question of whether such technologies can meet the everyday energy expectations of both energy suppliers and end users.

In order to determine the potential contribution which renewable energy technologies could make to reducing carbon emissions, specifically, and sustainable development, generally, an energy study of Sheffield was undertaken. This involved updating a previous energy study of Sheffield to provide a more recent account of energy demands and associated carbon emissions in Sheffield. Additionally, the potential contribution of energy efficiency measures in reducing demand and the availability and potential contribution of increasing local renewable energy supply were explored. By means of this case study for Sheffield, the procedure and importance of updating energy assessments has been demonstrated. Furthermore, the possibility of replicating this approach adopted here has been established.

The essential purpose of undertaking an updated energy assessment was to provide a meaningful framework in which to examine the potential deployment and contribution of renewable energy technologies in an urban area. The energy study provided the basis for identifying key areas of energy consumption and carbon emissions within Sheffield. It became apparent that the built environment was a significant sector as it was found to be responsible for two-thirds of total energy demand and two-thirds of associated carbon emissions in Sheffield. The remaining energy use and carbon emissions were attributed to the transport sector. Natural gas and electricity are the two main forms of delivered energy used by end users in Sheffield. However, it was shown that this has not always been the case. Comparison of the current study to earlier work carried out in 1992, indicates that both national and local changes have influenced energy and carbon emission patterns in Sheffield over the last eight years. The "dash for gas" in electricity generation combined with a shift in the economic base of Sheffield from heavy industry to the service industries were two of the main reasons why there was a 19% reduction in carbon emissions over this eight-year period. This suggests that, whilst national changes in the energy supply mix are influential, local factors must be taken into account in the evaluation of carbon emissions. It can be seen that regular local assessment becomes important if local communities are to take responsibility for their carbon emissions.

Using the energy study of Sheffield, the role of energy efficiency measures in reducing energy consumption and associated carbon emissions in buildings was also investigated, along with identifying local renewable energy resources available for exploitation under current and future economic conditions. The study concluded that, in combination with energy efficiency measures, renewable energy resources could significantly reduce dependency on imported fossil fuels and associated carbon emissions. In particular, renewable energy resources could meet almost 40% of the energy demands of energy efficient buildings and reduce associated carbon emissions by 50%. Overall, a reduction of 72% in carbon emissions could be achieved within Sheffield's built environment. Within the district of Sheffield, it was established that solar energy could make the greatest contribution to future energy supplies followed by local wind power, biomass energy and small-scale hydro resources. Using this evaluation of potential contribution, actual opportunities for the large-scale deployment of renewable energy technologies were outlined. PSD features could be added to buildings to enhance natural heating, cooling, lighting and ventilation. Solar hot water panels and biomass energy could provide heating for buildings. The latter could provide heating on an individual basis or through the utilisation of Sheffield's district-heating network. Adding PV panels to buildings, erecting wind turbines within the district boundary and installing small-scale hydro schemes could supply buildings with renewable electricity. It was suggested that as the replacement rate of new build is 1-2% per year, retrofitting existing buildings with renewable energy technologies may offer a more realistic way of reducing carbon emissions in the short to medium term.

Overall, the energy study demonstrated that renewable energy resources are available for exploitation within an urban area. Having established the possible potential of these resources, it was necessary to investigate what obstacles might be encountered in their actual deployment by undertaking a systematic analysis of the renewable energy technologies relevant to Sheffield. The solar energy technologies of PSD, active solar systems and PV were examined in turn followed by wind power, biomass energy and small-scale hydro. Firstly, the basic aspects, resource considerations and the technical and economic status of each technology were explored in order to determine whether these factors were influencing the uptake of renewable energy technologies. Then, using the relevant stakeholder demand criteria, the performance of each technology was evaluated against the expectations of stakeholders. This rigorous assessment of the issues facing the practical application of renewable energy technologies in Sheffield provided an important insight into the essential obstacles facing their deployment. Although there may be some outstanding technical issues, the renewable energy technologies considered here are largely mature and commercially available. Whilst current costs for some renewable energy technologies are high in comparison with conventional sources of energy, it is possible to envisage a future situation in which they are economically competitive. Hence, leaving economic considerations aside, it was necessary to consider whether other factors would be obstacles to the future deployment of renewable energy technologies in urban areas. Subsequent evaluation of renewable energy resources and technologies against stakeholder expectations indeed revealed that such obstacles might exist. In particular, it was discovered that there are questions surrounding the accessibility, ease of use, flexibility, convenience, reliability, consistency, affordability and quality of renewable energy technologies to varying degrees for both energy suppliers and end users. It was noted that people's perceptions, the lack of supply and demand, the lack of support infrastructure, limited awareness and knowledge, and the lack of confidence in renewable energy may be some of the wider issues which would affect the deployment of renewable energy technologies in Sheffield.

Faced with the many obstacles, complexities and challenges that were identified by this investigation, a series of measures was proposed to promote urban renewable energy use. Although each solution is presented separately, they form part of an integrated and co-ordinated approach to help increase the profile of renewable energy in Sheffield, create the right conditions in which stakeholders can be influenced to invest in renewable energy technologies and develop an infrastructure to support renewable energy developments. Measures which address land use planning, building stakeholder confidence in renewable energy technologies and increasing supply and demand have been put forward. In relation to land use planning, it has been proposed that introducing energy plans and considering energy as a material consideration for development are two key ways to improve the accessibility of renewable energy resources for utilisation by energy suppliers, specifically, and end users, generally. Energy plans could provide a framework in which local authorities identify general areas of search with a presumption in favour of renewable energy development. In combination with energy becoming a material consideration for development, energy plans could provide a mechanism for stakeholders to identify local opportunities and to become actively involved in energy generation using locally available resources.

In order for energy suppliers and end users to become more involved in local energy production, stakeholders need to be confident in renewable energy technologies and their application in the urban environment. As such, an integrated approach has been proposed to help remove uncertainty, lack of confidence and increase understanding and knowledge amongst stakeholders. It has been suggested that there is a need for better advertising and marketing, education and training, supporting infrastructure and demonstration, standardisation of products, providing guarantees and certification and integrating renewable energy retrofits into conventional building work. The evaluation of renewable energy technologies against stakeholder expectations suggests that most stakeholders are unlikely to be motivated by environmental and sustainability concerns. It has been proposed that by integrating renewable energy technologies into an attractive "lifestyle" package, advertising and marketing could be used to emphasise the non-energy benefits of renewable energy technologies. This means that the focus is placed on the comforts and lifestyle provided rather than the specific details of the technology used. It is also suggested that other means of communication be utilised to increase the profile of renewable energy technologies, for example, having large, city-centre refurbishment examples and developing television, radio and educational and cultural programmes. In order to increase the availability of skilled trade's people, training programmes are proposed together with the development and promotion of renewable energy business opportunities.

In addition to better advertising, promotion and education, this investigation has highlighted the need to make the interaction between the technology, the fuels and the stakeholder easier. It has been proposed that showrooms could be created in which customers can view and discuss renewable energy technologies with specialists as well as selling renewable energy alongside their conventional counterparts in existing shops. In light of possible stakeholder concerns regarding the consistency of using biomass energy, in particular wood fuel, the importance of producing standard products such as chips, pellets or briquettes has been emphasised. It has been suggested that creating a standard, consistent product may increase stakeholder confidence in wood fuel. In addition, technology guarantees and certification schemes have been proposed to help assure stakeholders that the technology will perform according to their expectations. Also, the possibility of integrating the installation of renewable energy technologies with existing building work is suggested. This may help to overcome problems of disruption and inconvenience and could also reduce the amount of building work needed and construction costs.

Although increasing stakeholder awareness and knowledge of renewable energy technologies is likely to stimulate supply and demand, there are additional mechanisms which could be put in place to promote the market for renewable energy technologies. At present, there is limited demand or incentives to invest in renewable energy sources and technology. The idea of extending the Renewables Obligation to include heat, which has been proposed by Friends of the Earth amongst others, is considered to be helpful. This market mechanism would help to create demand for renewable energy sources for heat production, particularly within the district heating network in Sheffield. In addition, changes to the existing Renewables Obligation are proposed. Lowering the threshold at which generators can receive ROCs could allow more small scale generators to take advantage of this support mechanism than is currently the case. Other fiscal incentives are also proposed including grant availability, particularly for PSD, tax breaks and reducing VAT payments on renewable energy technologies.

The deployment of renewable energy technologies on a large-scale in Sheffield would mean a significant transformation of current energy provision to a distributed network of small-scale generators. In order to manage a diverse group of energy suppliers, many of which are likely to be end users, and different levels of supply within the district, a new type of energy utility has been proposed. The energy utility would be required to manage internal supply and demand and would also be responsible for managing imported renewable energy supply to the district. One suggestion is that the energy utility could take the form of an ESCO, whereby individual end users are linked to a single energy supplier. This contractual relationship can offer many advantages including financial benefits, social inclusion for those normally excluded through fuel poverty, and the opportunity of investing in and utilising local renewable energy sources. This relationship could also involve the energy utility or ESCO renting roof space in Sheffield for electricity generation from PV roofs and managing ownership issues in relation to the development of small-scale hydro schemes in the district.

Using the stakeholder demand criteria, the interface between stakeholders and different energy systems has been investigated. The criteria have provided a means of identifying and assessing the nature of the obstacles facing current and future renewable energy developments. In addition, they have been used to measure the potential success of solutions by evaluating their ability to meet and fulfil stakeholder expectations. Although the stakeholder criteria will be influenced by changing stakeholder expectations over time, this approach could be replicated in other urban areas. Using the criteria would help to ensure that wider non-technical and non-economic issues are taken into consideration rather than focussing on technical and economic factors.

The deployment of renewable energy in Sheffield would also require the utilisation of energy carriers to link energy supply to demand. Current energy carriers used by Sheffield, namely electricity, gas and district heating, were also examined to establish their technical and economic status and to identify any key issues facing their utilisation in future renewable energy developments. As an alternative, it has been suggested that hydrogen could be used as an energy carrier in the future. However, this raises the question of whether hydrogen is a suitable and realistic option. In order to determine the role of hydrogen as an energy carrier, a systematic examination was undertaken based on the examination previously undertaken for each renewable energy technology. The basic aspects, resource considerations and technical and economic status of hydrogen were examined. Then, using the energy supplier and end user demand criteria, the performance of hydrogen was evaluated against the expectations of stakeholders. This assessment showed that electricity, gas networks and district heating are the most viable options in the short term for Sheffield. Well-established distribution infrastructures are in place which could be modified for use to link the supply of renewable electricity, gas and heat to demand. The utilisation of hydrogen is more problematic. If produced from renewable energy sources, "renewable" hydrogen could become an important energy carrier in the future. However, in the short to medium term, there are many questions surrounding the accessibility, ease of use, flexibility, convenience, reliability, consistency, affordability, quality and environmental sustainability of renewable hydrogen. In particular, its utilisation is limited by technical and economic difficulties in combination with many of the obstacles facing renewable energy technologies such as lack of supply and demand, lack of support infrastructure and lack of stakeholder confidence in the practical application of hydrogen.

Although there are questions over the use of renewable hydrogen, a number of measures were suggested to improve the prospects for the future use of hydrogen in towns and cities. Many of the measures suggested for renewable energy technologies could also be extended to promote renewable hydrogen, for example, advertising and promotion, education and training along with pilot studies and demonstration projects to increase consumer confidence in hydrogen. In particular, if hydrogen is "packaged," in a marketing sense, correctly, stakeholders may be more likely to accept hydrogen as an energy carrier as its utilisation will also bring other lifestyle benefits. However, significant research, development and testing of renewable hydrogen are needed before this can happen. This will require a significant investment to transform hydrogen away from the research and development stage towards its wider utilisation within buildings.

It is proposed that the move towards the greater use of renewable energy resources as a way of reducing carbon emissions and introducing greater sustainability into urban systems is possible. However, this is obviously not an easy task. Using Sheffield as a case study example has provided an insight into the many issues and complexities facing the deployment of renewable energy sources and technologies within the urban environment. It is apparent that a great deal of commitment would be required to transform energy provision from the existing centrally-based system to one in which a diverse range of locally-distributed plants and schemes within towns, cities and rural areas throughout the UK meet their own energy needs. However, if major problems from global climate change are to be avoided, the RCEP forecasts demonstrate that a very substantial shift in the energy base is needed in the UK (RCEP, 2000). This study has demonstrated that the potential exists for Sheffield and other UK cities to effect the required changes if the recommendations suggested here are implemented.

14.2 Recommendations for Further Work

Although some of the obstacles raised in this research may be specific to Sheffield, other obstacles are common issues facing renewable energy technologies generally. As such, all of the solutions suggested by this research could be extended to address the promotion of renewable energy technologies in other urban areas in the UK and elsewhere. In order to extend the conclusions from this research to other urban areas, the next step would be to communicate the findings of this research with key players in communities, such as Local Authorities, and produce articles and papers for release in journals and at conferences.

In terms of recommended further work, a key question that comes out of this research is whether the solutions suggested in Chapter 13 could be delivered collectively by means of an integrated approach, whether they would be effective, and whether they would conflict. As the current assessment was based upon a qualitative approach, the next step is to test the effectiveness of the solutions using quantitative research methods. Depending on the depth of such assessment, this research could be carried out in one study or in a series of studies. The aim of the work would be to investigate the effectiveness of the measure(s) in promoting the deployment of renewable energy technologies by their practical implementation within urban areas. Case study results for Sheffield could act as an essential basis for further research. This would allow the measure(s) to be investigated in detail on a local level. The wider implications for the UK and other countries could be drawn out in the conclusions.

The work would require a review of existing research in relation to the measures, which comprise of solutions associated with land use planning, namely energy plans and energy as a material consideration, solutions for building stakeholder confidence including advertising and marketing, supporting infrastructure and demonstration, standardisation of products, guarantees and certification and integrating building work, and solutions which address wider supply and demand, such as revisions to the Renewables Obligation, fiscal incentives and new supply and demand management. Additionally, solutions have been suggested in relation to the development and regulation of hydrogen in urban areas and these would have to be investigated. By using a variety of quantitative research methods including questionnaires and interviews, the effectiveness of the measures against the relevant stakeholder demand criteria could be assessed within existing decision-making and planning frameworks.

Using the land use planning solutions as an example, research could be directed towards assessing how effective other land use plans and land designations are in regulating and managing land use within urban areas and determining their impact on the type of development that takes place. Criteria could be produced as a means of assessment. Scenarios could be developed to suggest what the situation would be like if other land use designations and/or land use plans were not in place. This would provide a framework in which to examine the role of renewable energy plans and designations and to determine their influence within existing decision-making and planning frameworks. Questionnaires and interviews with decision makers, including planners, could be utilised to test out ideas and obtain feedback on the potential application of energy plans and the incorporation of energy as a material consideration. The effectiveness of these measures could be finally assessed against the stakeholder demand criteria. Once there is evidence that the solutions could work collectively and/or individually, a demonstration project could be initiated in Sheffield. This will provide practical experience and real results. This could then be extended into a pilot study, before practical implementation of the measure(s) take place within the UK. This would involve comparing each measure against existing approaches such as, for example, the advertising of a product or service. If existing decision-making and planning frameworks are found to be ineffective in delivering the solutions, alternative structures should be suggested and the practicality of using them investigated.

In addition to the built environment, transport is another area where further work is required. In particular, more work needs to be done on transport energy consumption patterns and associated carbon emissions in urban areas, perhaps drawing upon the energy assessment of the transport sector contained in this research and developing it more for Sheffield or other towns and cities. In line with this research, a full energy study of transport is required in which ways of reducing energy consumption and carbon emissions are identified together with increasing the use of renewable energy sources for transport applications. This would also need extending to include the use of hydrogen. Additionally, transport demand criteria could be developed for different stakeholders including private motorists and motor cyclists, public transport providers and passengers, as well as pedestrians and cyclists. By undertaking a full research study, technical, economic, non-technical and non-economic obstacles which prevent the development of sustainable urban mobility could be identified and practical solutions to these problems could be posed. Following on from this, research which tests the effectiveness of the solutions would be necessary. This would have the effect of actually addressing the many diverse and complex issues facing the energy and carbon management of the transport sector to date and scenarios for the future could be examined. Using a case study example, such as Sheffield, would allow these issues to be addressed in detail on a local level with the opportunity to draw out parallels with other urban areas in the UK and further afield.

APPENDIX A REVIEW OF ENERGY ASSESSMENT METHODOLOGIES

A1 Urban Energy Assessments

Urban energy assessments, or studies, provide important information on energy consumption and related carbon emissions within a defined area. This information can provide the basis for predicting future energy trends and carbon emissions. Within the UK, urban energy assessments have been produced for areas such as Newcastle-upon-Tyne (Newcastle City Council, 1992), Sheffield (Grant, 1993, 1994a, 1994b; Grant and Mortimer, 1995; Grant et al., 1994a, 1994b, 1994c, 1995a, 1995b; Kellett, 1993, 1994a, 1994b; Mortimer, 1993 and Mortimer et al., 1994), Conisbrough and Denaby (Grant and Kellett, 2001, 2002a, 2002b, 2002c) and Peterborough (Anon, 2002b). Urban energy assessments utilise a number of energy assessment methodologies to produce energy and carbon emission estimations. Energy assessment methodologies can be used to evaluate energy supply and demand, energy saving potential and renewable energy prospects within a defined area. This review examines three different types of energy assessment and their respective methodologies, namely baseline energy use and carbon emission assessments (Sections A2 and A3, respectively), energy efficiency assessments (Section A4) and renewable energy assessments (Section A5). Conclusions of the review are presented in Section A6.

A2 Baseline Energy Assessment

A2.1 Energy Demand Estimation

Baseline energy assessments identify current energy supply and demand within a defined area. There are three main methodologies used to estimate energy use, namely approximate estimations, comprehensive estimations and hybrid estimations.

A2.2 Approximate Baseline Energy Estimations

Approximate estimations of energy use national published statistics to pro rata energy consumption within a defined area. Pro rata is a term used to describe the process of producing statistics using comparable national and local statistics. One example of this approach is to produce national ratios for energy consumption based on population statistics which can be applied at a local level (Grant, 1994a). By following this method, a basic assessment of energy consumption within an area can be achieved. This technique is particularly useful where local data are unavailable. An approximate estimation of energy use can be produced relatively quickly and easily and the use of national statistics means that the energy study can be easily replicated. However, where local estimations are extrapolated from national statistics, local characteristics or variations in energy supply and demand are not identified. This can have important implications for further studies, for example, the calculation of associated carbon dioxide emissions.

A2.3 Comprehensive Baseline Energy Estimations

Comprehensive estimations provide a detailed and in-depth energy assessment using information collected from a range of individual and large energy end users, including domestic and industrial end users, and energy suppliers. This approach is based entirely upon the collection of local energy data, making comprehensive estimations difficult to execute. The energy study of Newcastle-upon-Tyne conducted by Newcastle City Council in 1992 is the closest example to a comprehensive study carried out in the UK (Newcastle City Council, 1992). Using a steering group of major end user and supplier representatives, relevant energy data was collected from a range of sources including the Local Authority, energy suppliers and public transport operators (Newcastle City Council, 1992). A wide range of energy assessment methodologies were applied including undertaking pilot energy surveys of housing stock to gather primary domestic energy consumption data (Newcastle City Council, 1992). However, where local data were unavailable, national statistics were used.

A2.4 Hybrid Baseline Energy Estimations

A2.4.1 Hybrid Estimations

Hybrid estimations produce detailed energy assessments within the limitations of available resources (Bennett and Newborough, 2001). National published statistics and local energy data collected from a wide range of sources are used to produce energy demand estimations. Two examples of this approach are examined below.

A2.4.2 MIRE Study

The MIRE study was produced for Sheffield by the Resources Research Unit of Sheffield Hallam University in 1992. The aim of the MIRE Study was to identify major energy consuming sectors within Sheffield for further examination at a later date (Mortimer et. al., 1994). Using national published statistics and local data including energy survey data of local buildings, estimates of energy use within the district were quickly compiled. This study used national statistics on population, energy use and employment to establish energy use within the domestic, business and industry and transport sectors. A range of energy assessment methodologies were applied to produce national energy consumption ratios based on numbers employed, floor area, number of domestic households and dwellings and number of vehicles/journeys. The national energy consumption ratios were then applied to Sheffield (Grant, 1994a). Using this approach, preliminary estimates of final energy consumption per sector and fuel type were produced. National published statistical data used for the estimations. National energy statistics were taken from DUKES (DTI, 1993), population statistics from the National Census (1991) (OPSC, 1991) and employment data from the National Online Manpower Information Service (NOMIS) (NOMIS, 1993, 1994) and the Standard Industrial Classification (SIC) system (HMSO, 1980).

A2.4.3 CADRE Project

The overall aim of the "Conisbrough and Denaby Renewable Energy Scheme" (CADRE) was to achieve net zero carbon dioxide emissions in the communities of Conisbrough and Denaby (Grant and Kellett, 2001). A baseline assessment of energy use provided a detailed estimation of energy use and carbon dioxide emissions within the area. Using information supplied by the Local Authority and primary energy use surveys of individual sites and buildings, a comprehensive assessment of land use and energy demand within the area has been produced (Grant and Kellett, 2001). From the baseline energy study (Grant and Kellett, 2001), it emerged that domestic properties in Conisbrough and Denaby consume more than twice as much coal as the national average. In turn, the domestic properties are responsible for producing more than the national average of carbon dioxide emissions. This has additional implications in terms of domestic energy and carbon dioxide management within the area (Grant and Kellett, 2001). Without the local data, the high level of coal consumption in the area would have remained undiscovered. Where local information was unavailable, regional and national published statistics were used. Using a wide range of energy assessment techniques, baseline energy consumption and carbon dioxide emissions were produced for the study area and were compared to the UK. This included a breakdown of energy use and carbon dioxide emissions for the domestic, industrial and commercial sectors within Conisbrough and Denaby. As energy supply and demand is constantly changing, baseline energy studies can only provide a picture of energy demand at a particular place and time. In order to determine future patterns or changes in energy consumption, projections based on different scenarios including economic changes, the adoption of energy efficiency measures or the use of renewable energy sources can be forecast. The CADRE project used projections of future energy demand by sector produced by the Department of Trade and Industry to calculate projected increases in energy demand (DTI, 1995). This assessment indicated that the current baseline is likely to move over the next twenty years with some sectors experiencing higher growth in energy demand than others (Grant and Kellett, 2001). Further CADRE assessments examine energy efficiency improvements and potential renewable energy opportunities in the area.

A2.5 Key Points

In essence, energy studies require a balance between data requirements, cost, time, reflecting local characteristics and accuracy of the study. The availability of local information and resource investment are important elements for producing accurate studies which reflect energy use within a defined area. Limited data sources and limited investment compromises the accuracy and local character of energy studies. The Newcastle-upon-Tyne study illustrates that key energy contacts, accessible local information and investment in the study are important elements in ensuring successful energy estimations (Newcastle City Council, 1992). Without these elements in place, the level of detail required by comprehensive estimations is difficult to achieve. Approximate and hybrid estimations offer an alternative way of assessing energy use within a defined area where local data is limited or unavailable.

A3. Baseline Assessment of Carbon Emissions

Carbon estimations can be undertaken on a local, regional or national level and provide a useful indication of community-wide carbon emissions. By using estimations of energy demand and carbon coefficients, carbon emissions can be calculated. Carbon dioxide coefficients indicate the amount of carbon per unit of delivered energy. The carbon content of different fuels varies and, as such, the amount of carbon dioxide released also varies. Table A1 provides carbon coefficients for delivered energy by fuel type in 2000 (Pout, MacKenzie and Bettle, 2002). The coefficients take into account indirect emissions from processing and production and direct emissions at the point of use (Pout, MacKenzie and Bettle, 2002). The coefficients do not include carbon emissions released during the construction of the plant. The coefficients are presented in kilograms of carbon per gigajoule (kgC/GJ). By multiplying the total consumption of each fuel type by the relevant coefficient, the amount of carbon released can be calculated.

Table A1 Carbon Coefficients for Delivered Energy by Fuel Type for 2000 (Pout, MacKenzie and Bettle, 2002)

Fuel Type	Carbon emission coefficient (kgC/GJ)
Coal	22.5
Coke	28.2
Coke Oven Gas	16.7
Other Solid Fuels	26.7
Oil Products	20.0
Natural Gas	14.6
Electricity	37.4

Table A1 shows that natural gas produces the lowest amount of carbon per unit burned and electricity the highest. The emission factors for electricity reflect the mix of fuels used to generate electricity. Electricity is generated from a wide range of energy sources, namely fossil fuels, nuclear energy and renewable energy sources. The energy source used affects the carbon emissions released during electricity generation. This is illustrated in Table A2 where the differences between carbon emissions from nuclear power, combined cycle gas turbine (CCGT) and coal-fired power plants are shown. The coefficients shown in Table A2 are based on 1998 data and are for illustrative purposes only. The coefficients do not include carbon emissions released during fuel processing and plant construction. Table A2 illustrates that electricity generated from a coal-fired power plant produces almost two-and-a-half times more carbon than a CCGT power plant. Carbon emission coefficients are extremely variable and are constantly changing due to variations in fuel grade, conversion efficiencies and fossil-fuel and non-fossil fuel generated electricity.

Table A2 Electricity Carbon Emission Coefficients (Mortimer et. al., 1998)

Electricity Source	Carbon emission coefficient (kgC/GJ)
Nuclear power plant	0
CCGT power plant	34
Coal-fired power plant	80

Modelling energy use and carbon emissions improves the accuracy of any estimation. On a national level, models such as the Non-Domestic building Energy and Emissions Model (N-DEEM), have been produced to assess current emissions, investigate ways of reducing emission levels and provide estimations of future emissions using scenarios on an ongoing basis (Pout, MacKenzie and Bettle, 2002). The N-DEEM model uses a wide range of information sources including building stock data, energy audits, information provided by Local Authorities and external surveys of non-domestic building stock. The information collected and analysed in nationally-based models can be used on a local basis. The energy consumption for different activities in different sectors per unit of floor area has been calculated. This is also referred to as the end-use consumption per unit floor area (Pout, MacKenzie and Bettle, 2002). By determining local non-domestic activities and floor areas, the national figures can be applied to a local area. Extrapolating national figures uses readily available information and provides an approximation of energy use and emissions in relation to national figures. On a local level, energy surveys of local buildings including domestic buildings can be undertaken. When using this approach, the local sample size is important. In communities which have a large percentage of one type of building, for example, Connisbrough and Denaby, figures for a "typical" building can be compiled and applied to the total number of buildings/floor area within the area (Grant and Kellett, 2001). In a city such as Sheffield, the large diversity of buildings would make this approach difficult. One option would be to undertake a large number of local surveys to obtain representative results for the local area. Although this approach would provide a useful indication of local consumption and carbon dioxide emission patterns, it would require a significant investment in time and money to undertake the surveys and evaluate local data.

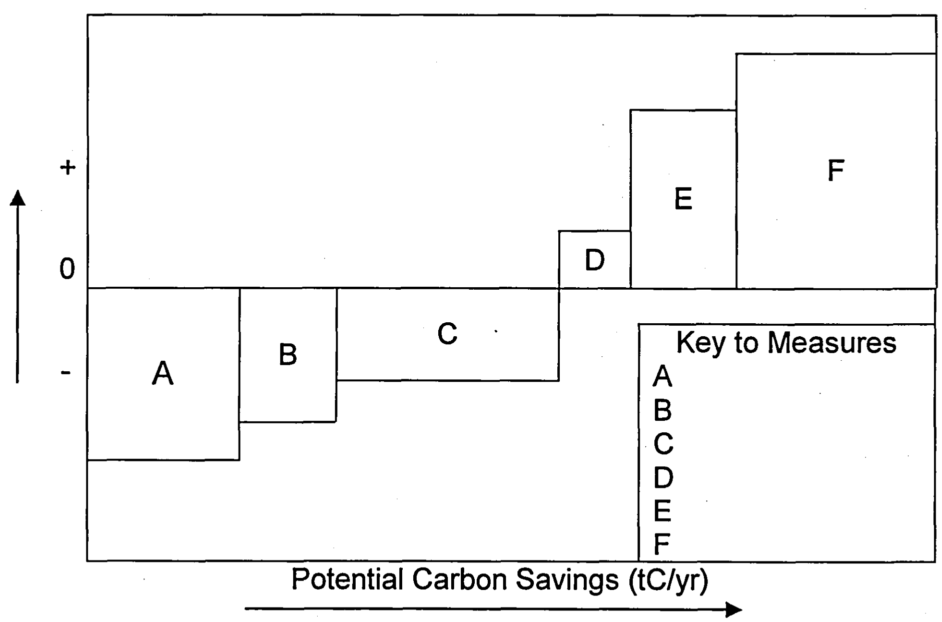
A4. Energy Efficiency Assessments

Energy efficiency assessments are produced for a wide variety of purposes including identifying ways of reducing energy consumption and carbon emissions through the introduction of energy efficiency options, identifying energy efficiency improvements and installation costs and providing the basis for implementing energy efficiency plans within a defined area (Grant and Kellett, 2002a). Energy efficiency options include technical measures such as replacing individual equipment and units including lights and refrigerators, improving insulation and installing control mechanisms, and non-technical measures to change occupant behaviour (Grant and Kellett, 2002a and Pout, MacKenzie and Bettle, 2002). The purpose of the assessment, the availability and quality of data and the level of investment in terms of time and monetary commitments affect the level of detail and analysis deployed and the accuracy and quality of the energy efficiency assessment.

There are two main approaches to energy efficiency assessments, namely comprehensive and approximate estimations. Comprehensive assessments are carried out on a case-by-case basis in which the energy consumption, carbon dioxide emissions and energy efficiency opportunities for individual buildings are assessed. Using this approach, the energy consumption and carbon dioxide emissions for the building can be modelled. This approach allows the level of investment and the cost effectiveness of specific energy efficiency measures to be accurately determined. Comprehensive assessments are in essence a "bottom-up" approach which produces detailed, in-depth and accurate quality assessments. With all energy efficiency assessments, a balance is required between data requirements, cost, time, accuracy and how representative the assessment is of the study area. Although comprehensive assessments produce accurate results, the approach is time-consuming and costly. An alternative approach would be to undertake an approximate energy efficiency assessment. Approximate assessments use generalisations and extrapolate energy efficiency data from national statistics. Although approximate assessments require less data and are quick and relatively cheap to produce, the approach cannot produce the same level of detail and accuracy as comprehensive assessments.

Energy efficiency assessments are an opportunity to reduce energy consumption and abate carbon dioxide emissions. Ideally, the best energy efficiency measures are those which are cost-effective, produce carbon savings and provide a net benefit financially (Mortimer et. al., 1998). One method of assessing the potential carbon savings and the cost-effectiveness of energy efficiency measures is to produce carbon abatement curves. The curves are a simple, clear and effective way of presenting data in a graphic format. In Figure A1, a schematic carbon abatement curve is presented. On the horizontal axis, the potential carbon emission savings for each measure is plotted in tonnes of carbon per year (tC/yr). The length of the measure indicates the amount of carbon that can be saved by its application. On the vertical axis, the net cost for each measure is plotted (£/tC). Each energy efficiency measure has a financial cost for installation and a financial saving from the use of the measure over its useful lifetime. Some measures also have operational costs. The net cost can be calculated by deducting the financial savings from the total financial costs, which are discounted over the useful lifetime of the measure, and dividing the result by the amount of carbon saved by the measure (Mortimer et. al., 1998). Discounting is a technique which enables cost flows which occur at different times to be compared on an equal basis by adjusting for the time value of money by means of the application of discount rates, which may be based on interest rates. Each measure is ranked from left to right in order of cost-effectiveness. The energy efficiency measures which appear below the zero cost line are cost-effective whilst those above are not cost effective.

Figure A1 Schematic Carbon Abatement Curve (Mortimer et. al., 1998)



The ranking of the energy efficiency options on the curve are important as this approach can be used to propose that the most cost-effective measures should be implemented first. It be noted that although the measures that appear above the zero cost line are not cost-effective, some measures may have large carbon savings as indicated by the horizontal length of each measure. Carbon dioxide abatement curves can be used as a basis for evaluating potential energy efficiency options (Grant, Kellett and Mortimer, 1994b). When considering ways of reducing carbon emissions within a tight financial framework, carbon abatement curves provide a useful way of selecting appropriate measures (Grant, Kellett and Mortimer, 1995b). When cumulative carbon savings are required, a combination of measures can be selected from the curve. Carbon abatement curves can also be used to assess the carbon dioxide savings of renewable energy sources in a defined area.

A5. Renewable Energy Assessments

A5.1 Renewable Energy Estimations

From renewable energy assessments, local renewable energy sources are identified, costs, energy availability and carbon savings are established and possibilities for importing renewable energy into a defined area may be explored. The quality of renewable energy assessments depends on the purpose of the assessment, the availability and reliability of local data, the level of investment in the study in terms of time and monetary resources and the methodologies used. There are two main approaches to renewable energy assessments, namely comprehensive and approximate assessments.

A5.2 Comprehensive Renewable Energy Assessments

Comprehensive assessments are site-specific and provide an in-depth, detailed and accurate assessment of available renewable energy at a particular site. The assessments often result in a list of possible schemes for local development. Comprehensive assessments are feasibility studies undertaken by developers. A greater level of time and monetary investment is required in order to collect accurate data and fully assess the commercial feasibility of a site. Primary data for the site is collected and the site monitored over a given period. For example, to establish accurate wind speeds on a site, a wind mast would be erected to record wind speeds over a set period. In addition to assessing the technical and economic viability of a site, comprehensive assessments address non-technical and non-economic considerations such as planning and legal issues. Although a site may be viable in technical and economic terms, local land designations can have significant implications for renewable energy developments as the designations affect the availability of the resource.

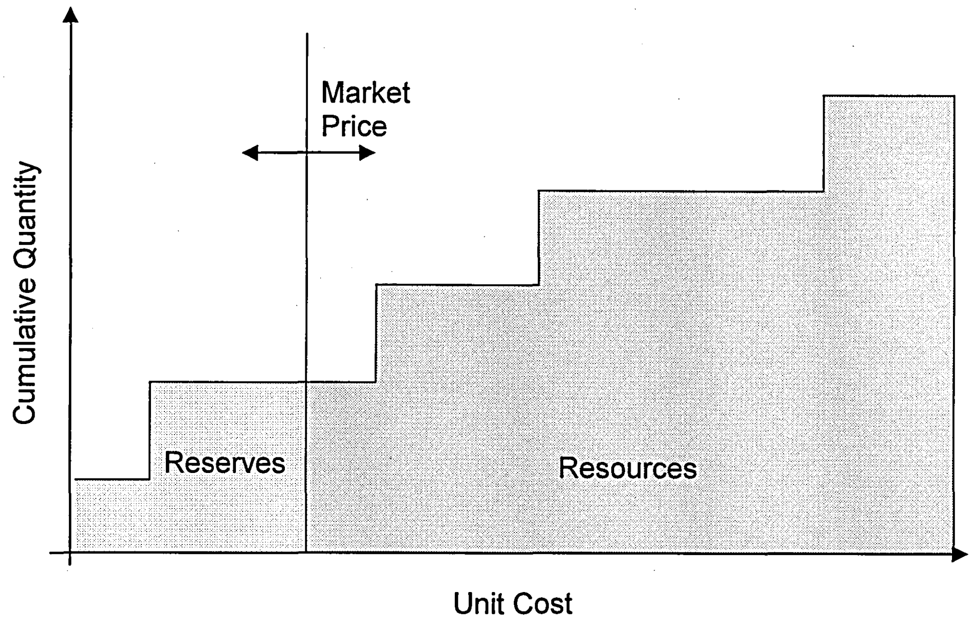
A5.3 Approximate Renewable Energy Assessments

Approximate assessments use available published data and modelling techniques to predict resource availability, estimate the economics of potential developments and indicate potential sites to exploit renewable energy sources. Approximate estimations are scoping studies which provide a broad view of local renewable energy potential within an area. A wide range of published data can be used, for example, the UK Wind Speed Data Software Package, which assesses wind energy potential within an area (ETSU, 1993). Using wind speeds based on actual readings at a limited number of recording stations, the database extrapolates wind speed over wider areas and uses models to account for differences in local topography. The database can be used to assess the average wind speed for any grid reference square in the UK. This approach is important when identifying potential sites for commercial development and, as such, provides a basis for comprehensive assessments.

A5.4 Resource Cost Curves

With all renewable energy assessments, it is important to consider economic issues. The economic feasibility of using renewable energy sources is subject to many variables such as changes in production costs and fluctuating market prices for energy. Resource cost curves are a method of presenting resource data within an economic context in a graphical format (Grant, Kellett and Mortimer, 1994b). As such, the curves provide the basis for further evaluation of potential renewable energy developments. Resource cost curves can be formulated in approximate and comprehensive assessments. However, the curves are mainly generated from approximate estimations as the data collected for comprehensive assessments is often confidential and sensitive. Figure A2 presents a schematic resource cost curve. On the horizontal axis, the unit cost of a given resource is plotted. On the vertical axis, the cumulative quantity of the available resource is plotted. The curve shows that the amount of available resources increases as the unit cost increases. A line to indicate the market price of resources has been added. The sources to the left of this line could be exploited under present economic conditions and, hence, are the reserves. Although a greater amount of resources are clearly available to the right of the line, the exploitation of these resources is not economically viable at present.

Figure A2 Schematic Resource Cost Curve (Grant, Kellett and Mortimer, 1994b)



The market price line and the curve are not static. Changes in the market price of resources will have an impact upon the economic viability of resource developments. The curve will change over time due to new discoveries, technological improvements and production cost changes (Grant, Kellett and Mortimer, 1994b).

A6 Conclusions

In conclusion, there are a number of different methodologies available for producing energy assessments of a defined area. Assessments of energy use and associated carbon emissions, energy efficiency measures and renewable energy opportunities can be produced. The methodology used can vary from approximate estimations using nationally available published statistics to detailed comprehensive assessments based on local data. Hybrid methodologies offer a viable alternative for producing a detailed assessment based on locally and nationally available data. Schematic carbon abatement curves and resource cost curves are a simple way of presenting information on energy efficiency improvements and renewable energy potential in a clear format. The type of methodology applied depends on a number of crucial factors, namely the intention of the energy study, the level of detail required and the availability and quality of information. Without a clear purpose to the energy study, the identification of information sources and the right investment in terms of time, money and effort, the quality of the study can be compromised.

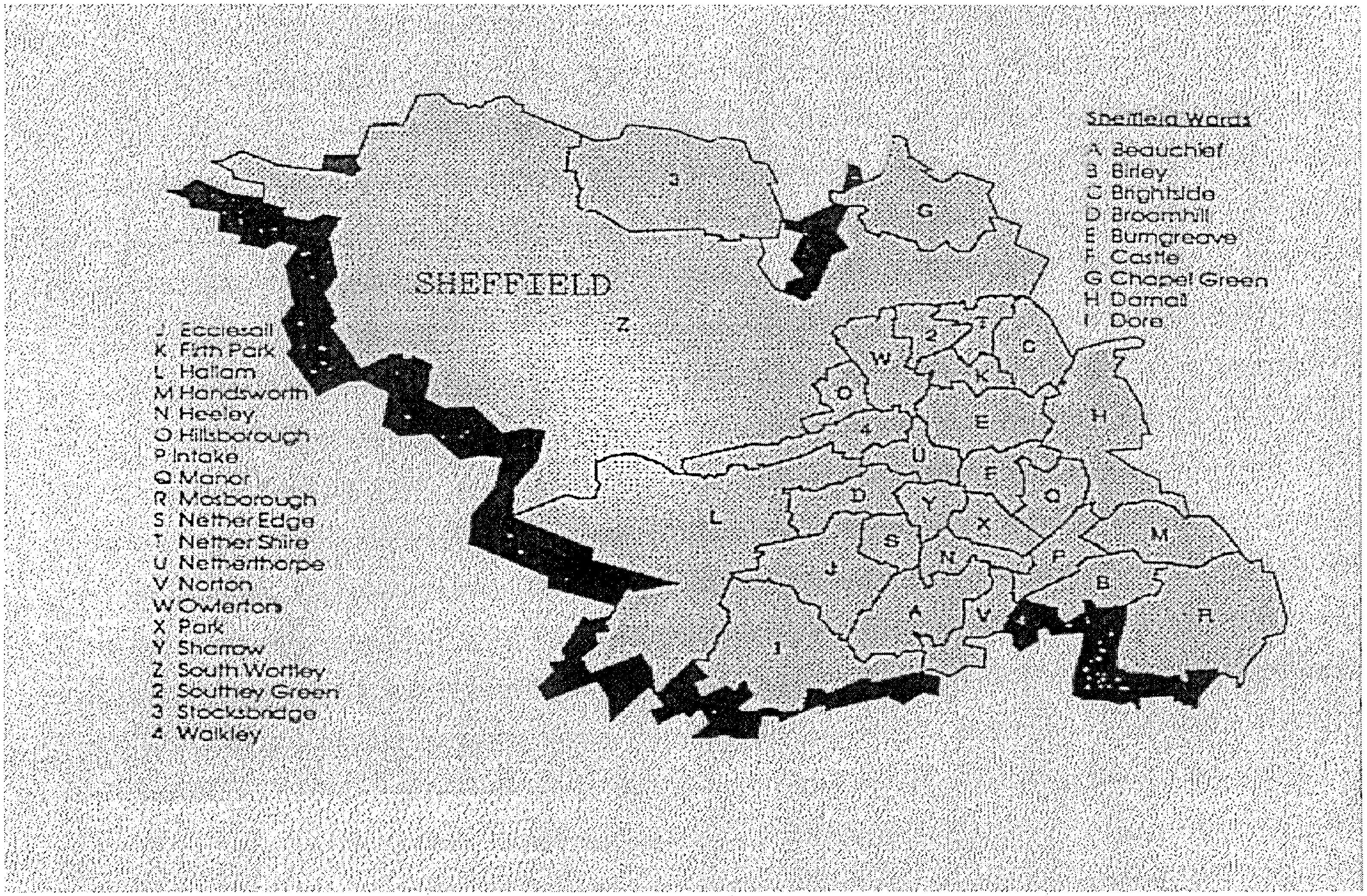
APPENDIX B BASELINE ASSESSMENT OF ENERGY USE AND CARBON EMISSIONS IN SHEFFIELD

B1 Hybrid Energy Assessment

A hybrid energy assessment methodology was adopted to derive local estimations of delivered energy consumption and associated carbon emissions within the District of Sheffield by fuel type and sector. This involved producing national energy consumption ratios in relation to the number of domestic dwellings, numbers employed, the number of vehicles in use and resident population figures and applied at a local level in Sheffield. A wide range of national and local statistical data on energy use, population, employment, domestic dwellings, transport and carbon emissions were used. The main source of information on energy use within the UK is the Digest of United Kingdom Energy Statistics (DUKES) (DTI, 2001a). The National Statistics Statbase (National Statistics, 2002a) contains population estimates. Information on national and local employment can be located in the Annual Abstract of Statistics (National Statistics, 2002b), on the National Online Manpower Information Service (NOMIS) (NOMIS, 2002) and from private communication with the Learning Skills Council (Swain, 2002). Domestic dwelling information was provided by the Office of the Deputy Prime Minister (ODPM, 2001, 2002). Information on transport was gathered from a wide range of sources including national publications (OPCS, 1991; National Statistics, 2000a, 2000b, 2001a, 2001b, 2002b; CSRB, 2001 and DFT, 2001), regional publications (SYPTE, 2000) and local information sources (Boyd, 2002). Carbon coefficients compiled by the BRE Energy Technology Centre have been used for the purposes of this study (Pout, Mackenzie and Bettle, 2002). National and local statistics were used to pro rata energy consumption within Sheffield.

Following a preliminary examination of data sources, the study area was defined and the baseline year of the study, the main stakeholders and the main fuel types consumed within Sheffield were identified. The study area is defined as the Local Authority district boundary of Sheffield as shown in Figure B1. This boundary definition was chosen as national energy data and local statistical information, such as employment data, are available for this administrative unit. The baseline year of the study was set at 2000 due to the availability of information. In particular, information collected for the 2001 UK census was unavailable at the time of the study. Although the majority of information derives from 2000 data, other sources of data are generally

Figure B1 Local Authority District Boundary of Sheffield



current to within two or three years. Previous estimations of energy consumption within Sheffield, contained within the MIRE study, have been used to produce a baseline of energy consumption and carbon emissions of Sheffield in 1992 (Grant, 1993, 1994a, 1994b; Grant, Kellett and Mortimer, 1994a, 1994b, 1994c, 1995; Grant and Mortimer, 1995; Kellett, 1993, 1994a, 1994b; Mortimer, 1993 and Mortimer, Kellett and Grant, 1994). The methodology used in the MIRE study forms the basis of the 2000 energy study of Sheffield. This approach was adopted in order to compare energy consumption patterns between 1992 and 2000.

Within Sheffield, the main end users were identified as the business and industrial sector, the domestic sector and the transport sector. The business and industrial sector represents many types of economic activities such as public administration activities including schools and hospitals, commercial activities and manufacturing of all types. The domestic sector comprises of all residential dwellings. Within the transport sector, there are three main modes available within Sheffield; road, rail and air. Road transport comprises of private cars and taxis, motorcycles, scooters and mopeds, buses and coaches, light good vehicles and heavy goods vehicles. Rail transport comprises of the national rail network and Supertram, Sheffield's light rail system. At the time of the study, Sheffield had a small airport which operated a limited number of services. Five fuel type categories of solid fuels, natural gas, oil products, electricity and renewables, were considered to be relevant in Sheffield and these were complied using the energy data contained in DUKES (DTI, 2001a). Solid fuels include coal and coke and oil products include petroleum products. Renewable energy refers to electricity produced from renewable energy sources such as solar and wind energy. Using carbon emission coefficients, estimations of carbon emissions were produced by sector and fuel type.

Baseline energy consumption in the UK and Sheffield were measured in terajoules (TJ). A TJ is a unit of energy equal to 10^{12} joules. A joule is a unit of energy equal to the energy released by an electrical current of 1 ampere driven by 1 volt for 1 second (DUKES, 2001).

1 TJ is equal to: 41.87 thousand tonnes of oil equivalent (ttoe)
3.6 gigawatt hours (GWh)
105.5 million therms (DUKES, 2001a).

Carbon dioxide emissions were measured in tonnes of carbon (tC). Carbon dioxide is realised when different fuels containing carbon are burnt, for example, coal, oil and natural gas. Different fuels have different carbon contents which affects the amount of carbon dioxide released. In order to calculate carbon emissions, carbon coefficients are used. Carbon coefficients indicate the amount of carbon released per unit of energy available (tC per TJ) either upon combustion of a fuel or through the generation of electricity (Pout et al, 2002).

The subsequent sections summarise the methodologies and results of energy use and carbon emission calculations within the business and industrial sector (Section B2), the domestic sector (Section B3) and the transport sector (Section B4). The methodology and results of carbon emission calculations for each sector are presented in Section B5. Section B6 summaries the methodology and results of the MIRE study of Sheffield. In the absence of carbon emission data for 1992, the approach adopted for estimating carbon emissions in this year is also contained within Section B6.

B2. Business and Industrial Energy Use

Business and industrial energy consumption estimations were based on national energy data (DTI, 2001a) and employment data (National Statistics, 2002b and Swain, 2002). This approach was adopted due to the extent, diversity, unavailability and confidentiality of local energy data within this sector. Industrial energy consumption data contained in DUKES and national employment data contained within the Annual Abstract of Statistics is subdivided according to the Standard Industrial Classification (SIC) system (CSO, 1992). In the UK, the SIC system groups economic activities of a similar nature into "industries". Under SIC, there are 17 broad sections (A-Q) which can be further subdivided into smaller sections. Table B1 provides a description of SIC sections A-Q. Although the SIC system is used to collate energy and employment data, differences in the way the data are presented required the formulation of aggregated industrial categories for the purpose of this study. The revised business and industrial sector categories used are presented in Table B2.

As illustrated in Table B2, Sections DJ and DK have been produced as a separate category to draw out local industrial and employment characteristics and allow for comparison with the earlier study on Sheffield. Under DUKES, mining and quarrying is classified as a fuel producer rather than final consumer of energy and has therefore been removed from the list (DTI, 2001a). In the preliminary examination, transport was identified as one of the three main end users in Sheffield and has also been removed from this list.

Table B1 Description of UK SIC Sections (CSO, 1992)

Section	Description
A	Agriculture, hunting and forestry
B	Fishing
C	Mining and quarrying
D	Manufacturing
E	Electricity, gas and water supply
F	Construction
G	Wholesale and retail trade, repair of motor vehicles, motorcycles and personal and household goods
H	Hotels and restaurants
I	Transport, storage and communication
J	Financial Intermediation
K	Real estate, renting and business activities
L	Public administration and defence; compulsory social security
M	Education
N	Health and social work
O	Other community, social and personal service activities
P	Private households with employed person
Q	Extra-territorial organisations and bodies

Table B2 Business and Industrial Categories (based on SIC 1992)

SIC Section	Description
A, B	Agriculture, fishing and forestry
DJ, DK	Manufacturing of metals
D, E	Other manufacturing
F	Construction
G, H, J, K	Commerce
L, M, N	Public administration
O-Q	Miscellaneous

Using the revised categories in Table B2, the total UK industrial energy consumption (DTI, 2001a) was divided by the number of people employed in the UK (National Statistics, 2002b). This produced a national industrial consumption ratio was then applied to the number of people employed within the business and industrial sector in Sheffield (Harrison, 2002). Within DUKES, a breakdown of industrial energy consumption by fuel type is provided (DTI, 2001a). By adopting a pro rata approach based on employment statistics, a breakdown of industrial energy consumption by fuel type was compiled for Sheffield as shown by Tables B3 to B7.

Table B3 Solid Fuel Consumption by the Business and Industrial Sector, Sheffield 2000

SIC	Description	UK				Sheffield	
		ttoe	TJ	No employed	TJ per person	No employed	Total TJ
A, B	Agriculture, fishing and forestry	5	209.35	320000	0.000654219	70	0
DJ, DK	Manufacturing of metals	1309	54807.83	885000	0.061929751	22440	1390
D, E	Other manufacturing	937	39232.19	3179000	0.012341047	17890	221
F	Construction	0	0	1171000	0	9040	0
G, H, J, K	Commerce	0	0	10764000	0	95120	0
L, M, N	Public administration	197	8248.39	6101000	0.001351973	58120	79
O-Q	Miscellaneous	6	251.22	1272000	0.0001975	10920	2
	Total	2454	102749	23692000	0.076474491	213600	1692

Table B4 Consumption of Oil Products by the Business and Industrial Sector, Sheffield 2000

SIC	Description	UK				Sheffield	
		ttoe	TJ	No employed	TJ per person	No employed	Total TJ
A, B	Agriculture, fishing and forestry	633	26503.71	320000	0.082824094	70	6
DJ, DK	Manufacturing of metals	402	16831.74	885000	0.019018915	22440	427
D, E	Other manufacturing	5242	219482.5	3179000	0.069041378	17890	1235
F	Construction	467	19553.29	1171000	0.016697942	9040	151
G, H, J, K	Commerce	495	20725.65	10764000	0.00192546	95120	183
L, M, N	Public administration	1145	47941.15	6101000	0.007857917	58120	457
O-Q	Miscellaneous	147	6154.89	1272000	0.00483875	10920	53
	Total	8531	357193	23692000	0.202204455	213600	2512

Table B5 Natural Gas Consumption by the Business and Industrial Sector, Sheffield 2000

SIC	Description	UK				Sheffield	
		ttoe	TJ	No employed	TJ per person	No employed	Total TJ
A, B	Agriculture, fishing and forestry	127	5317.49	320000	0.016617156	70	1
DJ, DK	Manufacturing of metals	3261	136538.1	885000	0.154280305	22440	3462
D, E	Other manufacturing	12506	523626.2	3179000	0.16471413	17890	2947
F	Construction	180	7536.6	1171000	0.006436038	9040	58
G, H, J, K	Commerce	3744	156761.3	10764000	0.014563478	95120	1385
L, M, N	Public administration	4680	195951.6	6101000	0.032117948	58120	1867
O-Q	Miscellaneous	2350	98394.5	1272000	0.077354167	10920	845
	Total	26848	1124126	23692000	0.466083222	213600	10565

Table B6 Renewable Energy Consumption by the Business and Industrial Sector, Sheffield 2000

SIC	Description	UK				Sheffield	
		ttoe	TJ	No employed	TJ per person	No employed	Total TJ
A, B	Agriculture, fishing and forestry	72	3014.64	320000	0.00942075	70	1
DJ, DK	Manufacturing of metals	0	0	885000	0	22440	0
D, E	Other manufacturing	364	15240.68	3179000	0.004794174	17890	86
F	Construction	0	0	1171000	0	9040	0
G, H, J, K	Commerce	0	0	10764000	0	95120	0
L, M, N	Public administration	81	3391.47	6101000	0.000555888	58120	32
O-Q	Miscellaneous	12	502.44	1272000	0.000395	10920	4
	Total	529	22149.23	23692000	0.015165812	213600	123

Table B7 Electricity Consumption by the Business and Industrial Sector, Sheffield 2000

SIC	Description	UK				Sheffield	
		ttoe	TJ	No employed	TJ per person	No employed	Total TJ
A, B	Agriculture, fishing and forestry	325	13607.75	320000	0.042524219	70	3
DJ, DK	Manufacturing of metals	2137	89476.19	885000	0.10110304	22440	2269
D, E	Other manufacturing	6848	286725.8	3179000	0.090193696	17890	1613
F	Construction	136	5694.32	1171000	0.004862784	9040	44
G, H, J, K	Commerce	5875	245986.3	10764000	0.02285268	95120	2174
L, M, N	Public administration	1948	81562.76	6101000	0.013368753	58120	777
O-Q	Miscellaneous	0	0	1272000	0	10920	0
	Total	17269	723053	23692000	0.274905171	213600	6880

B3 Domestic Energy Use

To derive estimates of domestic energy use in Sheffield, the total domestic energy consumption within the UK (DTI, 2001a) was divided by the number of dwellings in the UK (ODPM, 2001). This calculation produced a national dwelling energy consumption ratio which was then applied to the number of dwellings in Sheffield (Sheffield First, 1999). Within DUKES, domestic energy consumption by fuel type is provided. By adopting a pro rata approach based on the number of dwellings, a breakdown of domestic energy consumption by fuel type for Sheffield was compiled. The results of this calculation are shown in Table B8.

Table B8 Energy Consumption of Dwellings in the UK and Sheffield, 2000

	UK	Sheffield
Number of Dwellings	25,217,000	224,992
Total Energy Consumption (TJ)	1,960,898	17,496
Fuel Breakdown (TJ):		
Solid Fuel	80,977	723
Natural Gas	1,331,759	11,882
Oil Products	135,617	1,210
Electricity	402,664	3,593
Renewable energy (electricity)	9,881	88

This methodology was based on dwellings rather than households due to information availability. A dwelling can be defined as a unit of accommodation, for example, a house. A household relates to the number of people living at the same address, which can range from one person to a group of people (ODPM, 2002). Whilst household numbers are available for England, figures for the rest of the UK are limited (Harrison, 2002). It is important to note that this approach does not pick up local variations in energy consumption patterns. For example, Sheffield, once part of a large mining region, is likely to have higher than average levels of coal consumption, which will not be identified by this methodology.

B4 Transport Energy Use

B4.1 Transport Energy Demand

There are three main transport modes available within Sheffield: road, rail and air. Road transport comprises of private cars and taxis, motorcycles, scooters and mopeds, buses and coaches, heavy goods vehicles and light goods vehicles. Rail transport consists of the national rail network and Supertram, Sheffield's light rail system. The main transport fuels are petroleum derivatives, comprising of diesel, leaded and unleaded petrol. Although there are other fuels available, such as liquid petroleum gas and electricity for powering vehicles, there is limited available information on the use of these energy sources for transportation purposes. There are a number of common issues facing the calculation of energy consumption by transport modes within any defined area. The issues include the availability of national, regional and local transport statistics, variations in the way information is presented and the use of different definitions, boundaries and methodologies. Defining boundaries is particularly important to the allocation of energy consumption. Each mode of transport available in Sheffield can travel within, through, from and/or to the district. Without defining the boundary, it is difficult to define travel patterns and calculate the energy consumed by such movements. There are many ways to allocate transport energy consumption within an area including allocating transport energy consumption per person in residence in a defined area or to collectively allocate energy consumption to each transport mode starting its journey in Sheffield. With such issues in mind, there is a need within this study to allocate energy use and carbon emissions of transport to Sheffield. In order to derive estimations of energy consumption by transport modes in Sheffield, a pro rata approach based on national and local data, where available, was adopted for road, rail and air transport as summarised below.

B4.2 Road Transport

In order to estimate energy consumption of road transport in Sheffield, it was necessary to produce estimations on the number of vehicles within Sheffield. In the absence of 2001 Census data, vehicle projections were largely based on a pro rata approach using national and local data. Private car estimations were produced using local car ownership projections (SYPTE, 2000), 1991 car ownership multipliers (OPCS, 1991) and the number of households in Sheffield (ODPM, 2001). In 2000, there were 228,000 households in Sheffield (ODPM, 2001). Local car ownership projections were used to estimate the average number of households in Sheffield with no car, one car and two or more cars, as shown in Tables B9 and B10. In order to calculate how many households had two cars and three or more cars, 1991 census data was used to produce multipliers of car ownership as shown in Table B11 (OPCS, 1991). By using the 1991 multipliers, the number of households with two cars and three or more cars were calculated, as shown by Tables B12a and B12b.

Table B9 Local Household Car Ownership and Projections in Sheffield (National Statistics, 2000b)

Car Ownership Projections for 2001	No. of cars (%)		
	0	1	2+
Low	40	42	18
High	37	43	20
Average	38.5	42.5	19

Table B10 Number of Households with and without Cars in Sheffield, 2000

2001 Projections	No car	1 car	2+ cars	Total
Low (%)	91200 (40%)	95760 (42%)	41040 (18%)	228000 (100%)
High (%)	84360 (37%)	98040 (43%)	45600 (20%)	228000 (100%)
Average (%)	87780 (38.5%)	96900 (42.5%)	43320 (19%)	228000 (100%)

Table B11 Car Ownership in Sheffield in 1991 (OPCS, 1991)

Car ownership	Number of cars	%	Households with 2+ cars (%)
No car	94740	44.9	
1 car	83853	39.7	
2 cars	27552	13.1	85.1
3+ cars	4828	2.3	14.9
Total cars	153441	100	100

Table B12a Number of Households with Two or More Cars in Sheffield, 2000

Number of cars	Households with 2+ cars (%)	Projected number of households with 2+ cars			Total number of cars
		Low	High	Average	
2 cars	85	34925.04	38805.6	36865.32	73731
3+ cars	15	6114.96	6497.4	6454.68	19364
Total	100	41040	45600	43320	93095

Table B12b Car Ownership in Sheffield in 2000

Car Ownership	Number of Cars
1 car	96900
2 cars	73731
3+ cars	19364
Total cars	189995

Taxis numbers for Sheffield were obtained from the Taxi Licensing Section of Sheffield City Council as shown by Table B13 (Boyd, 2002). Taxi numbers for the year 2002 were used as figures for 2000 were unavailable.

Table B13 Number of Taxis in Sheffield (Boyd, 2002)

Type of Vehicle	Number of Taxis
Hackney carriages	402
Private hire	905
Total	1307

The number of motorcycles, mopeds and scooters vehicles licensed in the UK (CSRB, 2001 and National Statistics, 2000a) and population estimates were used to calculate the number of motorcycles, mopeds and scooters per person in the UK. This figure was then applied to the population of Sheffield as shown by Table B14.

Table B14 Number of Motorcycles, Mopeds and Scooters in Sheffield, 2000
(National Statistics, 2001 and CSRB, 2001)

	Great Britain	Northern Ireland	UK
Vehicles currently licensed in:	759292	14116	773408
UK population			59755700
Vehicles per person			0.012942832
Sheffield population			530103
No. of vehicles in Sheffield			6861

Although there are figures available on the number of buses, coaches, light goods vehicles and heavy goods vehicles licensed in Great Britain and Northern Ireland, differences with the way the information is presented make it difficult and complicated to estimate the number of such vehicles in the UK. As such, vehicle estimations for buses, coaches, light goods vehicles and heavy goods vehicles were not produced. Instead, energy consumption estimations for these modes of transport were produced using national transport petroleum consumption statistics (DFT, 2001), road transport petroleum consumption ratios (DFT, 2001) and population estimates.

Using national transport petroleum consumption statistics (see Table B15), national breakdowns of petroleum consumption by mode of road transport (see Table B16) and road transport motor spirit and petroleum derivatives (DERV) consumption ratios (see Tables B17 and B18), fuel consumption figures were produced for private cars and taxis, motorcycles, mopeds and scooters, buses and coaches, light goods vehicles, heavy goods vehicles, national rail and air transport. For private cars and taxis, the national petroleum consumption figure for private cars and taxis was divided by the number of such vehicles in the UK. This ratio was then applied to the number of private cars and taxis in Sheffield as shown by Table B19. This methodology was also adopted for calculating energy consumption by motorcycles, mopeds and scooters (see Table B20). For buses and coaches, the national fuel consumption figure for buses and coaches was divided by the UK population and then applied to the population of Sheffield. This was repeated for the calculation of energy consumption of light goods vehicles and heavy goods vehicles within Sheffield (see Table B21).

Table B15 National Transport Petroleum Consumption, 2000 (DFT, 2001)

Transport Mode/ Fuel Type	Million tonnes	%
Road Transport:		
Motor spirit (leaded)	1.51	4.1
Motor spirit (unleaded)	19.9	53.7
DERV	15.63	42.2
Total Road Transport Fuel Consumption	37.04	100
Rail Transport:		
Gas/diesel oil/fuel oil	0.43	97.7
Burning oil	0.01	2.3
Total Rail Transport Fuel Consumption	0.44	100
Air Transport:		
All aviation fuels	10.75	100
Water Transport:		
Gas/diesel oil	0.91	95.8
Fuel oil	0.04	4.2
Total Water Transport Fuel Consumption	0.95	100
Total Fuel Consumption for all Transport Modes	49.18	

Table B16 Petroleum Consumption by Road Transport, 2000 (DFT, 2001)

Transport Mode	Motor spirit (%)	Transport Mode	DERV (%)
Cars & taxis	95	Goods vehicles	68
Light goods vehicles	4	Buses & coaches	7
Other including motorbikes	1	Other including diesel cars & taxis	25
Total	100		100

Table B17 Road Transport Motor Spirit Consumption in the UK,

Transport Mode	Motor spirit - Unleaded		Motor spirit - Leaded		Total
	Million tonnes	%	Million tonnes	%	Million tonnes
Cars & taxis	18.905	95	1.4345	95	20.3395
Light goods vehicles	0.796	4	0.0604	4	0.8564
Other including motorbikes	0.199	1	0.0151	1	0.2141
Total	19.9	100	1.51	100	21.41

Table B18 Road Transport Petroleum Derivatives (DERV) Consumption in the UK

Transport Mode	Million tonnes	%
Goods vehicles	10.6284	68
Buses & coaches	1.0941	7
Other including diesel cars & taxis	3.9075	25
Total	15.63	100

Table B19 Energy Consumption by Private Cars and Taxis in the UK and Sheffield, 2000

	Number of cars & taxis	Million tonnes	TJ
UK	24,964,442	24	1017441
Sheffield	191302	0.186210393	7797

Table B20 Energy Consumption by Motorcycles, Mopeds and Scooters, 2000 (National Statistics, 2001 and CSRB, 2001)

Motorcycles, mopeds and scooters currently licensed in:	
Great Britain	759292
Northern Ireland	14116
UK	773408
UK population	59755700
Vehicles per person	0.012942832
Sheffield population	530103
Number of vehicles in Sheffield	6861.034195
Motor spirit consumed by vehicles in UK (tonnes)	214100
Motor spirit per vehicle in UK (tonnes)	0.27682672
Motor spirit consumed by vehicles in Sheffield (tonnes)	1899.317593
Motor spirit consumed by vehicles in Sheffield (TJ)	80

Table B21 Energy Consumption by Buses, Coaches, Light Goods Vehicles and Heavy Goods Vehicles, 2000

Heavy goods vehicles:	
UK DERV consumption (million tonnes)	10.6284
UK DERV consumption (tonnes)	10628400
UK population	59755700
Sheffield population	530103
DERV per person in the UK (tonnes)	0.183060223
DERV consumed in Sheffield (tonnes)	97040.77314
DERV consumed in Sheffield (TJ)	4061
Light goods vehicles:	
UK Motor spirit (leaded and unleaded) consumption (million tonnes)	0.8564
UK Motor spirit consumption (tonnes)	856400
Motor spirit per person in the UK (tonnes)	0.014750365
Motor spirit consumed in Sheffield (tonnes)	7819.212498
Motor spirit consumed in Sheffield (TJ)	327
Bus and coach travel:	
UK bus and coach DERV consumption (million tonnes)	1.0941
UK bus and coach DERV consumption (tonnes)	1094100
DERV per person in the UK (tonnes)	0.018844435
DERV consumed in Sheffield (tonnes)	9989.491352
DERV consumed in Sheffield (TJ)	418

B4.3 Rail Transport

To derive estimations of energy consumption by rail transport in Sheffield, a pro rata approach based on track length was adopted. The national rail petroleum consumption figure was divided by the length of rail track in the UK (CSRB, 2001 and Williams, 2002). This figure was then applied to the total length of track in the district of Sheffield. Although there are some general statistics available on Sheffield's Supertram, including length of track and passenger numbers, energy consumption figures are unavailable. In the absence of local and national data, energy consumption statistics for Greater Manchester's Metrolink have been used (Barry et al, 1998). Both the Metrolink and Supertram systems both operate on 750 volt direct current from overhead contact wires (Barry et al, 1998 and DFT, 2001). Based on the assumption that the energy consumption of Metrolink is typical of a light rail system, estimations of energy consumption for Supertram in Sheffield were calculated based on passenger kilometres. Passenger kilometres are estimates made from ticket sales (DFT, 2001). The energy consumption figure per passenger kilometre (Barry et al, 1998) was multiplied by the number of passenger kilometres travelled on the Supertram system for the year 2000/01 as shown by Table B22 (DFT, 2001).

Table B22 Energy Consumption of Rail Transport, 2000

Rail Transport:	
Total UK track length (km)	16929
Total Sheffield track length (km)	91
Petroleum consumed by rail transport in the UK (tonnes)	440000
Petroleum consumed by rail transport in Sheffield (tonnes)	2365.1722
Petroleum consumed by rail transport in Sheffield (TJ)	99
Light Rail:	
Passenger kilometres (2000/2001)	38000000
Load factor	30.1
Energy (MJ/pkm)	0.98
Energy used by Supertram (MJ)	37240000
Energy used by Supertram (TJ)	37
Total Energy Consumption by all Rail Transport in Sheffield (TJ)	136

B4.4 Air Transport

In order to produce estimations of the energy consumption of air travel in Sheffield, an approach was adopted based on domestic flights from Sheffield City Airport. Although the information available was for the year 2002 as opposed to the baseline year, the calculations provide an indication of the energy consumption of aviation by Sheffield. At the time of the study, the Airport operated scheduled flights to Belfast, Northern Ireland and Jersey, Channel Islands. Using flight schedules (Anon, 2002b) and an air distance calculator (Anon, 2002c), the total length (kilometres) of outbound flights was calculated. Estimations of energy consumption were based on outbound flights only. Return flights were not included in the calculations as it was assumed that the refuelling of the aeroplanes formed part of the energy consumption of the destination airport rather than Sheffield City Airport. The British Airways Jet Stream 41 aeroplane was used for scheduled flights at Sheffield City Airport. Using fuel consumption statistics for the Jet Stream 41 (EMEP/CORINAIR, 2001), fuel consumption figures for the airport were calculated. The total outbound kilometres travelled was multiplied by the average fuel consumption per kilometre as shown by Table B23. Although private flights and helicopter flights are available at Sheffield City Airport on demand, the necessary information required to carry out estimations of energy consumption of such flights was unavailable. As such, these activities are not included in the assessment.

Table B23 Energy Consumption of Air Travel in Sheffield, 2000

Jet Stream 41:	
Average fuel consumption (kg/km)	0.922155917
Outbound Flights to Belfast:	
Sheffield to Belfast (air km)	320
No. of flights per year	624
Fuel consumption (kg)	184136
Outbound Flights to Jersey:	
Sheffield to Jersey (air km)	481
No. of flights per year	22
Fuel Consumption (kg)	9758
Air Travel in Sheffield:	
Total Fuel Consumption (kg)	193894
Total Fuel Consumption (TJ)	8

B5 Carbon Emissions

Carbon emissions were calculated using carbon emission coefficients compiled by the BRE Energy Technology Centre (Pout, Mackenzie and Bettle, 2002). Table B24 lists the carbon emission coefficients for delivered energy by fuel type for 2000. The coefficients are presented in terms of tonnes of carbon (tC) per terajoule (TJ). Carbon emissions are directly related to the type and amount of fuel used within an area. As the fuel mix of electricity production changes over time, associated carbon emissions also change. In addition, the amount of total delivered energy consumed by a sector affects the amount of carbon emissions released. Using simple arithmetic, the carbon emissions for different fuels were calculated by multiplying the total fuel consumption within each sector by the relevant carbon coefficient as shown by Tables B25, B26 and B27. The fuel breakdown used in the baseline study comprises of solid fuels which includes coal and manufactured fuels such as coal and breeze, oil products, natural gas, electricity and renewable energy sources which includes solar energy, wind power, hydro and biomass energy sources and waste. For the purposes of this study, renewable energy sources, including waste, are classified as carbon neutral.

Table B24 Carbon Emission Coefficients for Delivered Energy by Fuel Type

Fuel Type	Carbon emission coefficient (tC/TJ)
Coal	22.5
Coke	28.2
Coke Oven Gas	16.7
Other Solid Fuel	26.7
Oil Products	20.0
Natural Gas	14.6
Electricity	37.4

Table B25 Carbon Emissions of the Business and Industrial Sector, Sheffield 2000

Fuel Type	TJ	%	tC	%
Solid fuels	1691	7.8	43635	8.6
Oil products	2511	11.5	50227	9.9
Natural gas	10565	48.5	154246	30.5
Renewable energy (electricity)	123	0.6	0	0
Electricity	6880	31.6	257312	51
Total	21770	100	505420	100

Table B26 Carbon Emissions of Domestic Dwellings, Sheffield 2000

Fuel Type	TJ	%	tC	%
Solid fuels	723	4.2	17060	5.3
Oil products	1210	6.9	24200	6.9
Natural gas	11882	67.9	173477	49.5
Renewable energy (electricity)	88	0.5	0	0
Electricity	3593	20.5	134378	38.3
Total	17496	100	349115	100

Table B27 Carbon Emissions of the Transport Sector, Sheffield 2000

Fuel Type	TJ	%	tC	%
Solid fuels	0	0	0	0
Oil products	12790	99.7	255800	99.5
Natural gas	0	0	0	0
Renewable energy (electricity)	0	0	0	0
Electricity	37	0.3	1384	0.5
Total	12827	100	257184	100

B6. Energy Use and Carbon Emissions in Sheffield in 1992

B6.1 Energy Assessment

In 1994, the Resources Research Unit of Sheffield Hallam University produced preliminary estimations of energy use in Sheffield for the year 1992 as part of the MIRE study. Using a hybrid energy assessment methodology, published energy statistics and local data on population and employment figures were used to estimate energy consumption for the Local Authority district of Sheffield. Overall energy consumption was sub-divided into three key sectors, namely the business and industry, domestic and transport sub-sectors. In order to compare and contrast energy use and carbon emissions in Sheffield between 1992 and 2000, the earlier work was updated. A detailed breakdown of energy use in the business and industrial sector by SIC category and fuel type was produced. In the absence of a breakdown of carbon emissions by sector and fuel type, new carbon estimations for each sector in 1992 were produced. The following sections summarise the original and revised methodologies used and results for energy use in Sheffield's business and industrial sector (Section B6.2), the domestic sector (Section B6.3) and the transport sector (Section B6.4) in 1992. Section B6.5 summarises the approach used to estimate carbon emissions for Sheffield in 1992 and presents the results of the calculations.

B6.2 Business and Industrial Energy Use

Preliminary estimations of energy consumption by the business and industrial sector in 1992 were produced by economic activity only. In order to compare energy consumption in this sector between 1992 and 2000, it was necessary to produce new estimations of energy use by economic activity and fuel type. Using the methodology adopted for the assessment of energy use in this sector in 2000, as detailed in Section

B2, breakdowns of energy use by fuel type and economic activity for 1992 were produced. The following tables contain the results of this assessment for coal (Table B28), coke and breeze (Table B29), coke oven gas (Table B30), oil products (Table B31), natural gas (Table B32), renewable energy (Table B33) and electricity (Table B34).

Table B28 Coal Consumption by the Business and Industrial Sector, Sheffield 1992

		UK			Sheffield	
SIC	Description	ttoe	TJ	No employed	No employed	Total TJ
A, B	Agriculture, fishing and forestry	8	334.96	279000	70	0
DJ, DK	Manufacturing of metals	170	7117.9	269000	5575	148
D, E	Other manufacturing	1494	62553.78	3594000	39089	680
F	Construction	0	0	911000	9700	0
G, H, J, K	Commerce	124	5191.88	7184000	92100	275
L, M, N	Public administration	489	20474.43	1420000	0	0
O-Q	Miscellaneous	431	18045.97	5718000	12961	41
	Total	2716	113718.9	19375000	159495	1144

Table B29 Coke and Breeze Consumption by the Business and Industrial Sector, Sheffield 1992

		UK			Sheffield	
SIC	Description	ttoe	TJ	No employed	No employed	Total TJ
A, B	Agriculture, fishing and forestry	0	0	279000	70	0
DJ, DK	Manufacturing of metals	3515	147173.1	269000	5575	3050
D, E	Other manufacturing	14	586.18	3594000	39089	6
F	Construction	0	0	911000	9700	0
G, H, J, K	Commerce	0	0	7184000	92100	0
L, M, N	Public administration	88	3684.56	1420000	0	0
O-Q	Miscellaneous	14	586.18	5718000	12961	1
	Total	3631	152030	19375000	159495	3057

Table B30 Coke oven gas Consumption by the Business and Industrial Sector, Sheffield 1992

		UK			Sheffield	
SIC	Description	ttoe	TJ	No employed	No employed	Total TJ
A, B	Agriculture, fishing and forestry	0	0	279000	70	0
DJ, DK	Manufacturing of metals	500	20935	269000	5575	434
D, E	Other manufacturing	0	0	3594000	39089	0
F	Construction	0	0	911000	9700	0
G, H, J, K	Commerce	0	0	7184000	92100	0
L, M, N	Public administration	0	0	1420000	0	0
O-Q	Miscellaneous	34	1423.58	5718000	12961	3
	Total	534	22358.58	19375000	159495	437

Table B31 Consumption of Oil Products by the Business and Industrial Sector, Sheffield 1992

		UK			Sheffield	
SIC	Description	ttoe	TJ	No employed	No employed	Total TJ
A, B	Agriculture, fishing and forestry	857	35882.59	279000	70	9
DJ, DK	Manufacturing of metals	812	33998.44	269000	5575	705
D, E	Other manufacturing	2836	118743.3	3594000	39089	1291
F	Construction	897	37557.39	911000	9700	400
G, H, J, K	Commerce	1206	50495.22	7184000	92100	1641
L, M, N	Public administration	2455	102790.9	1420000	0	0
O-Q	Miscellaneous	0	0	5718000	12961	0
	Total	9063	379467.8	19375000	159495	4046

Table B32 Natural Gas Consumption by the Business and Industrial Sector, Sheffield 1992

		UK			Sheffield	
SIC	Description	ttoe	TJ	No employed	No employed	Total TJ
A, B	Agriculture, fishing and forestry	111	4647.57	279000	70	1
DJ, DK	Manufacturing of metals	1521	63684.27	269000	5575	1320
D, E	Other manufacturing	5343	223711.4	3594000	39089	2433
F	Construction	103	4312.61	911000	9700	46
G, H, J, K	Commerce	4603	192727.6	7184000	92100	3752
L, M, N	Public administration	3768	157766.2	1420000	0	0
O-Q	Miscellaneous	32	1339.84	5718000	12961	3
	Total	15481	648189.5	19375000	159495	7555

Table B33 Renewable Energy Consumption by the Business and Industrial Sector, Sheffield 1992

		UK			Sheffield	
SIC	Description	ttoe	TJ	No employed	No employed	Total TJ
A, B	Agriculture, fishing and forestry	72	3014.64	279000	70	1
DJ, DK	Manufacturing of metals	0	0	269000	5575	0
D, E	Other manufacturing	0	0	3594000	39089	0
F	Construction	0	0	911000	9700	0
G, H, J, K	Commerce	14	586.18	7184000	92100	35
L, M, N	Public administration	64	2679.68	1420000	0	0
O-Q	Miscellaneous	103	4312.61	5718000	12961	10
	Total	253	10593.11	19375000	159495	46

Table B34 Electricity Consumption of the Business and Industrial Sector, Sheffield 1992

		UK			Sheffield	
SIC	Description	ttoe	TJ	No employed	No employed	Total TJ
A, B	Agriculture, fishing and forestry	331	13858.97	279000	70	3
DJ, DK	Manufacturing of metals	1297	54305.39	269000	5575	1125
D, E	Other manufacturing	3483	145833.2	3594000	39089	1586
F	Construction	150	6280.5	911000	9700	67
G, H, J, K	Commerce	4473	187284.5	7184000	92100	2988
L, M, N	Public administration	2193	91820.91	1420000	0	0
O-Q	Miscellaneous	0	0	5718000	12961	0
	Total	11927	499383.5	19375000	159495	5769

B6.3 Domestic Energy Use

Estimations of domestic energy use were produced by dividing the total domestic energy consumption for the UK by the number of dwellings in the UK. This ratio was then applied to the number of dwellings in Sheffield in 1992 as shown by Table B35. No revisions to these data were necessary as a breakdown of the different fuels consumed by the sector was already provided.

Table B35 Comparison of Energy Consumption of Dwellings in the UK and Sheffield, 1992 (Grant, 1994a)

	UK	Sheffield
Number of Dwellings:	23,557,365	220,970
Total Energy Consumption:	1,893,523	17,761
Fuel Breakdown:		
Solid Fuel	222,935	2,091
Natural Gas	1,202,245	11,277
Oil Products	115,213	1,081
Electricity	353,130	3,312
Renewable energy	0	0

B6.4 Transport Energy Use

Due to the time-consuming nature of producing estimations of transport energy use, no revisions were undertaken for this sector. In 1992, preliminary estimations of transport energy use were based on national ratios of transport energy use and the number of vehicles in use in Sheffield (Grant, 1994a). Three groups of transport mode were identified as cars and taxis, public road transport and private road haulage. For cars and taxis, the national average private fuel consumption per car in UK was multiplied by number of cars owned by Sheffield's resident population. Local taxi numbers were assumed to be the same as the national ratio of private cars to taxis. Fuel consumption estimates for public road transport were based on the number of public transport vehicles owned in the UK, national diesel fuel consumption by public road transport and national and local population statistics. Using national fuel consumption data for goods vehicles and national and local population figures, energy consumption by private road haulage vehicles was calculated. The results of this preliminary estimation of transport energy use are shown in Table B36.

Table B36 Transport Energy Consumption in Sheffield 1992 (Grant, 1994a)

Transport Mode	Total Oil Products (TJ)
Private Cars and Taxis	7,983
Public Transport	432
Light and Heavy Goods Vehicles	4,470
Total	12,885

B6.5 Carbon Emissions

Carbon emissions were calculated using carbon coefficients for the year 1992 for coal, oil products, natural gas and electricity as shown in Table B37. In the absence of carbon coefficients for other solid fuels, such as coke and breeze, carbon coefficients for the year 2000 were used as shown in Table B38. All carbon coefficients are presented in terms of tonnes of carbon (tC) per terajoule (TJ). Using simple arithmetic, the carbon emissions for different fuels were calculated by multiplying total energy consumption by each sector and fuel type by the relevant coefficient.

Table B37 Carbon Emission Coefficients for Delivered Energy by Fuel Type for 1992 (Grant et al, 1994c)

Fuel Type	Carbon emission coefficient (tC/TJ)
Coal	24.2
Oil Products	27.2
Natural Gas	15.1
Electricity	60.0

Table B38 Carbon Emission Coefficients for Coke and Breeze and Other Solid Fuels, 2000 (Pout et al., 2002)

Fuel Type	Carbon emission coefficient (tC/TJ)
Coke and breeze	28.2
Other solid fuels	26.7

As a breakdown of solid fuel consumption within the domestic sector was unavailable, national domestic solid fuel consumption figures (DTI, 1993) were used to produce consumption ratios of coal, coke and breeze and other solid fuels as illustrated by Table B39. By applying these ratios to the domestic solid fuel consumption figures for Sheffield in 1992, estimates of associated carbon emissions were produced as shown by Table B40. Table B41 summarises total estimated carbon emissions for the domestic sector in Sheffield in 1992. The carbon emissions of the business and industrial sector and the transport sector are provided in Tables B42 and B43, respectively.

Table B39 Domestic Solid Fuel Use in the UK in 1992 (DTI, 1993)

Type of Solid Fuel	Million tonnes	%
Coal	4.18	65
Coke and breeze	0.26	4
Other solid fuels	1.99	31
Total	6.43	100

Table B40 Carbon Emissions of Solid Fuel Consumption, Sheffield 1992

Type of Solid Fuel	TJ	%	tC
Coal	1359	65	32893
Coke and breeze	84	4	2357
Other solid fuels	648	31	17307
Total	2,091	100	52557

Table B41 Carbon Emissions of Domestic Dwellings, Sheffield 1992

	UK		Sheffield	
	TJ	tC	TJ	tC
Total Energy Consumption/ Carbon Emissions:	1,893,523	48,078,964	17,761	450,963
Fuel Breakdown:				
Solid Fuel	222,935	5,603,471	2,091	52,557.1
Natural Gas	1,202,245	18,153,900	11,277	170,282.7
Oil Products	115,213	3,133,793	1,081	29,403.2
Electricity	353,130	21,187,800	3,312	198,720
Renewable energy	0	0	0	0

Table B42 Carbon Emissions of the Business and Industrial Sector, Sheffield 1992

Fuel Type	TJ	tC
Coal	1143.594	27675
Coke and breeze	3057.852	86231
Coke oven gas	437.1028	11671
Renewable energy	45.49058	0
Natural gas	7554.898	114079
Electricity	5769.567	346174
Oil Products	4045.813	110046
Total	22054.32	695876

Table B43 Transport Carbon Emissions, Sheffield 1992

Transport Mode	Energy Consumption (TJ)	Carbon Emissions (tC)
Private Cars and Taxis	7,983	217,133
Public Transport	432	11,759
Light and Heavy Goods Vehicles	4,470	121,571
Total	12,885	350,463

APPENDIX C ENERGY EFFICIENCY ASSESSMENT

C1 Approximate Energy Assessment

This appendix evaluates the potential reduction of energy demand through energy efficiency measures. Following the examination of current energy use and associated carbon emissions in Sheffield in the year 2000, buildings were identified as the main consumers of energy and carbon emissions (Appendix B). Approximately two-thirds of total delivered energy consumption and carbon emissions are attributed to buildings. The remaining third is attributed to transportation. As such, buildings offer a significant opportunity to reduce energy demand and carbon emissions in the district. Using generalisations and extrapolated energy efficiency data from national statistics (DEFRA, 2002; EA, 2002 and EST, 2002), an approximate estimation of potential energy and carbon savings in buildings was produced. Any potential savings were compared against the baseline energy and carbon emission assessment of Sheffield for the year 2000. It is important to note that although this approach is relatively quick to use and requires less data, it cannot produce a comprehensive, detailed and wholly accurate energy efficiency assessment. Using an approximate approach provides a general indication of potential savings across the sector as a whole. Due to the approximate nature of the approach, it does not highlight variations in energy efficiency potential which differ from building to building.

In order to maintain consistency with the other appendices, the same definition of the study area, the year of the study, main energy sectors, main fuel types and units of measurement have been used. These terms are defined in Section B1 of Appendix B. The following sections summarise the methods and results of energy efficiency assessments for the business and industrial sector (Section C2) and the domestic sector (Section C3). In Section C4, overall energy consumption and carbon emissions with energy efficiency improvements are presented.

C2 Business and Industrial Sector

There are many problems facing the analysis of potential energy efficiency savings in the business and industrial sector due to the many different types of buildings which are used for a wide range of economic activities such as retail, education and manufacturing. As such, potential energy efficiency savings can vary considerably.

This has been demonstrated by work on the Conisbrough and Denaby Renewable Energy (CADRE) Scheme project carried out by the Resources Research Unit of Sheffield Hallam University in 2001. It emerged that potential energy efficiency savings of between 10% and 18% were found to be possible within the commercial sector and 5% to 16% in public sector buildings and infrastructure (Grant and Kellett, 2002a). In order to provide an indication of potential energy and carbon savings within the business and industrial sector in Sheffield in 2000, national energy efficiency targets for industry were used (EA, 2002). Since 2000, the industrial sub-sector has experienced a trend of 10% improvement in energy efficiency overall (EA, 2002). This trend is forecast to continue up to 2020. Based on this trend, it has been assumed that energy savings of 10% can be achieved within the industrial sub-sector in Sheffield. In the absence of energy efficiency estimations for business activities, this ratio was also applied to the business sub-sector. Carbon emissions for each fuel type have been calculated by multiplying the total fuel figure by the relevant carbon coefficient as shown in Table C1. Tables C2 and C3 show the energy and carbon savings by fuel type for the industrial and the business sub-sectors, respectively.

Table C1 Carbon Emission Coefficients for Delivered Energy by Fuel Type, 2000

Fuel type	Carbon emission coefficient (tC/TJ)
Coal	22.5
Coke	28.2
Coke oven gas	16.7
Other solid fuel	26.7
Oil products	20.0
Natural gas	14.6
Electricity	37.4

Table C2 Energy Efficiency Assessment for the Industrial Sub-sector

Fuel Type	Energy Consumption		Carbon Emissions	
	Before energy efficiency	After energy efficiency	Before energy efficiency	After energy efficiency
	TJ	TJ	tC	tC
Solid fuels	1610	1449	41550	37395
Oil products	1662	1496	33239	29915
Natural gas	6409	5768	93568	84211
Renewable energy	86	77	0	0
Electricity	3882	3494	145199	130679
Total	13649	12284	313556	282200

Table C3 Energy Efficiency Assessment of the Business Sub-sector

Fuel Type	Energy Consumption		Carbon Emissions	
	Before energy efficiency	After energy efficiency	Before energy efficiency	After energy efficiency
	TJ	TJ	tC	tC
Solid fuels	81	73	2084	1876
Oil products	849	764	16989	15290
Natural gas	4156	3740	60678	54610
Renewable energy	37	34	0	0
Electricity	2998	2698	112113	100902
Total	8121	7309	191864	172678

C3 Domestic Sector

Unlike the business and industrial sector, it is possible to allocate domestic energy use by end use and fuel type (DEFRA, 2002). Additionally, national estimations on household energy efficiency savings have been produced (EST, 2002). However, the analysis of potential energy efficiency savings in the domestic sector is problematic. It is difficult to estimate the percentage of dwellings which are energy efficient, and to what extent, and those which are not. In order to be consistent with the analysis of energy efficiency in the business and industrial sector whilst providing a general indication of potential domestic energy savings, national energy efficiency targets for the domestic sector were used (PIU, 2002). Trends have shown that there have been improvements in domestic energy efficiency in recent years and that there are significantly more opportunities for energy efficiency in this sector (EST, 2002). In a recent report it was suggested that domestic energy efficiency could be improved by 20% by 2020 (PIU, 2002). This ratio has been applied to the baseline domestic energy consumption and carbon emission data for Sheffield in 2000. Table C4 shows the energy and carbon savings by fuel type which could be achieved in the domestic sector. Carbon emissions have been calculated using the carbon coefficients presented in Table C1.

Table C4 Energy Efficiency Assessment for the Domestic Sector

Fuel Type	Energy Consumption		Carbon Emissions	
	Before energy efficiency	After energy efficiency	Before energy efficiency	After energy efficiency
	TJ	TJ	tC	tC
Solid fuels	723	578	17060	14923
Oil products	1210	968	24200	19360
Natural gas	11882	9506	173477.2	138782
Renewable energy	88	70	0	0
Electricity	3593	2874	134378.2	107503
Total	17496	13996	349115.4	280568

C4 Overall Energy Consumption and Carbon Emissions

In Table C5, the results of the energy efficiency assessments of the business and industrial and domestic sector are collated. Energy consumption and carbon emissions are subdivided by fuel type. Table C5 shows that after energy efficiency improvements, the domestic sector is the largest consumer of energy within Sheffield, followed by the industrial sub-sector and the business sub-sector. The domestic sector and the industry sub-sector are jointly responsible for the largest share of carbon emissions, followed by the business sub-sector.

C5 Energy Consumption and Carbon Emissions of Buildings with Energy Efficiency Sheffield 2000

Fuel Type	Sector (TJ and tC)						Total	
	Business		Industry		Domestic			
	TJ	tC	TJ	tC	TJ	tC	TJ	tC
Solid fuels	73	1876	1449	37395	578	14923	2100	54194
Oil products	764	15290	1496	29915	968	19360	3228	64565
Natural gas	3740	54610	5768	84211	9506	138782	19014	277604
Renewable energy	34	0	77	0	70	0	181	0
Electricity	2698	100902	3494	130679	2874	107503	9067	3390834
Total	7309	172678	12284	282200	13996	280568	33590	735447
Sector share of total (%)	22	24	36	38	42	38	100	100

APPENDIX D RENEWABLE ENERGY ASSESSMENT OF SHEFFIELD

D1 Approximate Energy Assessment

Following the examination of current energy use and associated carbon emissions in Sheffield in 2000 (Appendix B) and ways of reducing energy demand in buildings through energy efficiency measures (Appendix C), it is necessary to look at the prospects for utilising local renewable energy resources in Sheffield to lower carbon emissions. At present, buildings consume approximately two-thirds of total delivered energy in Sheffield and are responsible for two-thirds of associated carbon emissions. It has been estimated that the vast majority of delivered energy consumed by buildings comes from fossil fuel sources (Appendix B and C). Introducing energy efficiency measures can lower energy consumption within buildings and associated carbon emissions (Appendix C). By substituting the remaining energy supply with energy produced from local renewable energy sources, carbon emissions could be substantially lowered across Sheffield. Data on local renewable energy supply, produced for the MIRE study, and the outcomes of the energy efficiency assessment of Sheffield in 2000 forms the basis of this assessment. An approximate approach was adopted in order to compare potential renewable energy supply with current energy demands. This approach provides a general indication of available renewable energy supply and potential carbon savings that could be achieved in Sheffield. However, due to the approximate nature of this approach, a comprehensive and detailed analysis cannot be produced.

The terms and definitions and units of measurement used here consistent with the Appendices B and C. Details on the definition of the study area and other terminology can be found in Section B1 of Appendix B. In order to identify the available renewable energy supply in Sheffield, Section D2 summarises the approach and results of the MIRE study. Detailed discussion of the methodology and outcomes of the MIRE assessment are discussed elsewhere (Grant, Kellett and Mortimer, 1994b, Grant, Kellett and Mortimer et al, 1994 and Grant, Kellett and Mortimer, 1995). Based on the findings of the MIRE study, Section D3 summarises the methods and results of the renewable energy assessment of Sheffield in 2000. In Section D4, overall energy and carbon savings for buildings in Sheffield are presented.

The Resources Research Unit of Sheffield Hallam University produced the MIRE study in 1992. National and local data and modelling techniques were used to identify local renewable energy sources, predict resource availability, estimate economic feasibility and identify potential sites for development in Sheffield and the surrounding area. Using standard resource assessment techniques, four available renewable energy sources were identified as available for exploitation in Sheffield, namely solar energy, wind power, small-scale hydro power and biomass energy (Grant, Kellett and Mortimer, 1994b and Grant, Kellett and Mortimer et al, 1994c). The results of the MIRE renewable energy assessment are summarised in Table D1.

Table D1 Renewable Energy Resources in Sheffield

Renewable Energy Source	Resource Base (TJ/ year)	Resources (TJ/ year)	Reserves (TJ/ year)
Solar energy	2,200,000	8,262	400
Wind power	6,100	2,808	60
Biomass energy	5,000	2,291	0
Small-scale hydro	1,200	90	20
Total	2,212,300	13,451	480

Using standard resource techniques, the available resource in a given area can be subdivided into three categories; the resource base, resources and reserves. The resource base is the total amount of energy available from a given source. Under most circumstances, it is impossible to exploit the entire resource base. Technological issues, in particular the efficiency of renewable energy technologies to collect and convert energy into useful forms of energy such as heat and light, affect the utilisation of the resource base (Elsayed and Mortimer, 2001). Resources can be defined as "the part of the resource base which could be developed under present or future economic circumstances using existing or modified current technology" (Grant, Kellett and Mortimer, 1994b). Under such circumstances, the renewable energy resources, which could be exploited now or in the future, are significantly less than the resource base, as illustrated by Table D1. In addition to technological and economic issues, the MIRE examination of renewable energy resources also addressed physical constraints. For example, when looking at the available wind power resource, the proximity of housing to the siting of wind turbines was examined (Grant, Kellett and Mortimer, 1994b). Technological advances and changing energy prices affect the availability of resources and reserves. Reserves can be defined as "that part of the resources which have been proved to exist and which could be exploited under present economic circumstances" (Grant, Kellett and Mortimer, 1994b). As such, reserves are essentially dynamic in nature due to fluctuating prices. As prices change and resource use becomes financially feasible, the size of resources changes very quickly (Grant, Kellett and Mortimer, 1994b). A schematic illustration of this situation is provided in Section A5.4 of Appendix A. In addition to economic issues, commercial considerations also affect the availability of reserves. For example, environmental considerations such as land designations and the ability to gain planning permission affect the feasibility of renewable energy developments (Grant, Kellett and Mortimer, 1994b).

D3 Renewable Energy Assessment of Sheffield, 2000

D3.1 Renewable Energy Resources

As illustrated by the MIRE study, the two most important classifications of renewable energy sources are resources and reserves. These terms indicate the practical potential of utilising the resources base and the economic feasibility of utilising renewable energy in the current energy market. Although the commercial exploitation of renewable energy reserves is important, it is only relevant when considering exploitation of renewable energy at the present time (Grant and Kellett, 2002b). Since ways of increasing the utilisation of renewable energy supply over the longer term are being investigated here, the calculation of renewable energy resources forms the basis of this analysis. The following sections summarise the methods used to apply the results of the MIRE renewable energy assessment to current energy demands in Sheffield. Estimations of energy demand in Sheffield after energy efficiency reductions are used as the basis of this assessment (Appendix C). It is important to note that although the MIRE study was conducted in 1992, the available renewable energy resources at that time have been applied to energy estimations of Sheffield in 2000.

D3.2 Renewable Energy Supply

In order to estimate carbon savings that could be achieved by utilising local renewable energy resources, it was necessary to establish how renewable energy could be utilised by buildings in Sheffield. As illustrated by Table D1, solar energy is the largest renewable energy resource available within Sheffield. The MIRE study illustrated that solar energy could provide buildings with heat or electricity. The roof space and fa| ades of buildings could be installed with either active solar hot water heating systems or PV cells for electricity generation (Grant, Kellett and Mortimer, 1994b). By taking data from the MIRE study, it was possible to breakdown the solar resource into solar application, suitable buildings, type of useful energy (output), energy supply (TJ/year) and share of solar resource as shown in Table D2.

Table D2 Solar Energy Supply in Sheffield

Solar Application	Suitable Buildings	Type of Useful Energy	Energy Supply (TJ/year)	Share of Solar Resource (%)
PV panels	Roofs of industrial buildings	Electricity	2643.8	32
PV panels	Roofs and facades of business buildings	Electricity	2478.6	30
Active solar (hot water) systems	Roofs of domestic buildings	Heat	2313.3	28
PV panels	Motorway earthworks	Electricity	862.2	10
Total			8262	100

In addition to solar energy, wind power, biomass energy and small-scale hydro power are also available for exploitation in Sheffield. As summarised in Table D3, these resources could be utilised to supply energy consumers with electricity or heat.

Table D3 Wind Power, Biomass Energy and Small-scale Hydro Power Supply in Sheffield

Renewable Energy Resource	Type of Useful Energy	Energy Supply (TJ/year)
Wind power	Electricity	2808
Biomass energy	Heat	2291
Small-scale hydro power	Electricity	90
Total		5189

Although it is difficult to foresee the extent to which sector would utilise energy from renewable energy resources, it was necessary to allocate this potential energy supply to each sector. In the case of electricity, it was assumed that renewable electricity from wind power and small-scale hydro power resources would be allocated where needed. Electricity generated from solar applications would be applied as set out in Table D2. Space and water heating are important requirements of all buildings. As such, biomass energy supply was subdivided equally amongst the business sub-sector, industrial sub-sector and domestic sector. Table D4 summarises the total renewable energy heat and electricity supply which could be utilised in Sheffield. As the updated energy study of Sheffield for 2000 focusses on buildings, the use of PV for motorway earthworks has been excluded from this assessment.

Table D4 Breakdown of Renewable Energy Resources by Sector, Sheffield 2000

Renewable Energy Resource	Sector (TJ)			Total (TJ)
	Business	Industrial	Domestic	
Solar energy: Solar energy breakdown: Electricity Heat	 2478.6	 2643.84	 2313.36	7436
Wind power (electricity)	-	-	-	2808
Small-scale hydro (electricity)	-	-	-	90
Biomass energy (heat)	763.6	763.6	763.6	2291
Total (TJ)				12625

Using the outcomes of the energy efficiency assessment of buildings in Sheffield, it has been estimated that natural gas and electricity are the two main fuels and sources of carbon emissions in Sheffield (Appendix C). Whilst electricity will be used for a wide range of electrical-based services, the majority of natural gas is likely to be used for space and water heating within buildings. In order to try and reduce the consumption of natural gas and non-renewable electricity in Sheffield, this assessment has focused on substituting natural gas and conventional electricity supply with heat and electricity, respectively, from renewable energy resources. The methods and results of this assessment are provided in the following sections. The business and industrial sector and the domestic sector are addressed in turn.

D3.3 Business and Industrial Sector

By looking at Tables D3 and D4, it is clear that renewable energy could supply the business sub-sector with 763.6 TJ of heat (biomass energy) and 2478.6 TJ of electricity (PV) a year. For industrial energy use, 763.6 TJ of heat (biomass energy) could be utilised together with 2643.84 TJ of electricity (PV). In order to estimate carbon savings from utilising this renewable energy supply, it was necessary to offset the available renewable energy supply against the energy demand of energy efficient buildings in the business and industrial sector in Sheffield (see Table D5). Firstly, the biomass energy contribution was deducted from natural gas consumption. As solar energy is the largest available resource in Sheffield, it was assumed that all of this potential should be utilised. Renewable electricity, generated from PV panels, was deducted from current electricity demand. Any remaining electricity demand was offset using electricity produced from small-scale hydro power and wind power resources. The outcome of this renewable energy assessment is provided in Table D6.

Table D5 Energy Consumption and Carbon Emissions of Buildings with Energy Efficiency in the Business and Industrial Sector

Fuel Type	Sector (TJ and tC)				Total	
	Business		Industry			
	TJ	tC	TJ	tC	TJ	tC
Solid fuels	73	1876	1449	37395	1522	39271
Oil products	764	15290	1496	29915	2259	45205
Natural gas	3740	54610	5768	84211	9508	138821
Renewable energy	34	0	77	0	111	0
Electricity	2698	100902	3494	130679	6192	231581
Total	7309	172678	12284	282200	19593	454878

Table D6 Energy Consumption and Carbon Emissions of Buildings with Energy Efficiency and Renewable Energy Supply in the Business and Industrial Sector

Fuel Type	Business		Industry		Total	
	TJ	tC	TJ	tC	TJ	tC
Solid fuels	73	1876	1449	37395	1522	39271
Oil products	764	15290	1495	29915	2259	45205
Natural gas	2977	43460	5005	73062	7982	116522
Renewable energy	3495	0	4335	0	7830	0
Electricity	0	0	0	0	0	0
Total	7309	60626	12284	140372	19593	200998

D3.4 Domestic Sector

Within domestic buildings, the majority of natural gas consumption is used for space and water heating purposes (DEFRA, 2002). Utilising active solar hot water systems and biomass energy could displace 2313.3 TJ and 736.6 TJ respectively of natural gas consumption. In order to estimate carbon savings from utilising this renewable energy supply, it was necessary to offset this supply against the energy demand of energy efficient buildings in the domestic sector in Sheffield, as shown in Table D7. Firstly, the energy supply from active solar systems was deducted from natural gas consumption, followed by the contribution from biomass energy. Renewable electricity from small-scale hydro power and wind power resources were then offset against current domestic electricity demands. Table D8 shows the carbon savings by fuel type for the domestic sector following this renewable energy assessment.

Table D7 Energy Consumption and Carbon Emissions of Buildings with Energy Efficiency in the Domestic Sector

Fuel Type	Domestic	
	TJ	tC
Solid fuels	578	14923
Oil products	968	19360
Natural gas	9506	138782
Renewable energy	70	0
Electricity	2874	107503
Total	13996	280568

Table D8 Energy Consumption and Carbon Emissions of Buildings with Energy Efficiency and Renewable Energy Supply in the Domestic Sector

Fuel Type	Domestic	
	TJ	tC
Solid fuels	578	14923
Oil products	968	19360
Natural gas	6429	93863
Renewable energy	4975	0
Electricity	1046	39104
Total	13996	167250

D4 Overall Carbon Savings in the Built Environment

In Table D9, the results of the renewable energy assessments of the business and industrial sector and the domestic sector are provided. Energy consumption and carbon emissions are subdivided by fuel type. Table D9 shows that renewable energy could make a significant contribution to lowering carbon emissions in Sheffield. In particular, renewable electricity could meet all the electrical demands of the business and industrial sector. However, the greatest contribution lies within the domestic sector, whereby a combination of renewable heat and electricity could significantly reduce emissions from this sector.

Table D9 Energy Consumption and Carbon Emissions of Buildings utilising Local Renewable Energy Resources, Sheffield 2000

Fuel Type	Business		Industry		Domestic		Total	
	TJ	tC	TJ	tC	TJ	tC	TJ	tC
Solid fuels	73	1876	1449	37395	578	14923	2100.138	54194.15
Oil products	764	15290	1496	29915	968	19360	3228.236	64564.71
Natural gas	2977	43460	5005	73062	6429	93863	14409.97	210385.6
Renewable energy	3495	0	4335	0	4975	0	12805.54	0
Electricity	0	0	0	0	1046	39104	1045.553	39103.69
Total	7309	60626	12284	140372	13996	167250	33589.44	368248.1

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